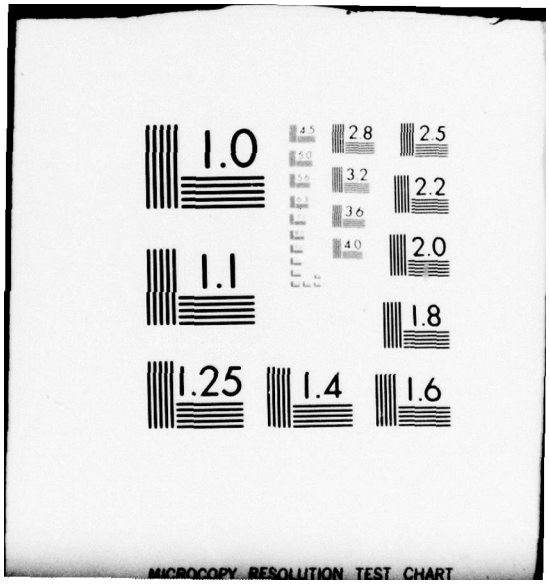
AD-A073 357 RAYTHEON CO WAYLAND MA EQUIPMENT DIV F/G 9/2
PAVE PAWS MODERN PROGRAMMING DATA COLLECTION SYSTEM.(U)
JUN 79 B H SCHEFF, W B VODGES, N R HALL F30602-77-C-0141
UNCLASSIFIED RADC-TR-79-137 NL

1 OF 2
AD A073857


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
7.1
8.0
9.0
10.0
MICROCOPY RESOLUTION TEST CHART

RADC-TR-79-137
Final Technical Report
June 1979

PAVE PAWS MODERN PROGRAMMING DATA COLLECTION SYSTEM

Raytheon Company

Benson H. Scheff
W. B. Vogdes
N. R. Hall

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

This report has been reviewed by the RADC Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-79-137 has been reviewed and is approved for publication.

APPROVED: Deane F. Bergstrom

DEANE F. BERGSTROM
Project Engineer

APPROVED: Alan R. Barnum

ALAN R. BARNUM
Assistant Chief
Information Sciences Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (ISIE) Griffiss AFB NY 13441. This will assist us in maintaining a current mailing list.

Do not return this copy. Retain or destroy.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: RADC-TR-79-137	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)*: PAVE PAWS MODERN PROGRAMMING DATA COLLECTION SYSTEM.	5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report Jul 77 - Feb 79
	6. PERFORMING ORG. REPORT NUMBER: N/A
7. AUTHOR(s): Benson H. Scheff, W. B. Vogdes, N. R. Hall	8. CONTRACT OR GRANT NUMBER(s): F30602-77-C-0141
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Raytheon Company, Equipment Division, Wayland MA 01778	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 63728F, 25280301, 03
11. CONTROLLING OFFICE NAME AND ADDRESS: Rome Air Development Center (ISIE), Griffiss AFB NY 13441	12. REPORT DATE: June 1979
	13. NUMBER OF PAGES: 91
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: Same	15. SECURITY CLASS. *(of this report)*: UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

Same

DDC RECEIVED AUG 31 1979 C

18. SUPPLEMENTARY NOTES

RADC Project Engineer: Deane F. Bergstrom (ISIE)

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Software Engineering
Modern Programming Techniques
Computer Software

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report describes the software development technologies which were utilized on the PAVE PAWS project and the techniques which were implemented to collect data to support on-going independent technology studies. At the request of the contracting agency, the emphasis of this report is on describing the software technology used on PAVE PAWS and providing an assessment of the effectiveness of those techniques.

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

388 201

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF APPENDICES

LIST OF FIGURES

EVALUATION

The PAVE PAWS is a phased array warning system designed to detect submarine launched ballistic missiles. In addition to real time mission requirements for the detection and characterization of SLBM's, the PAVE PAWS system implementation provides capabilities for simulating the mission functions, generation of scenarios for simulation, and a data reduction system. All the above system functions necessitated the development of computer software for both real time and non-real time capabilities.

A system requirement called for the use of modern programming and software engineering tools and methods for all system software development. In response to this requirement, Raytheon/IBM selected and employed a complete set of modern programming techniques for PAVE PAWS software development and management. These tools and procedures included a Program Support Library (PSL), pre-compilers to translate structured source code, use of graphic design methods and Program Design Language (PDL), Chief Programmer Team operations, structured design and code reviews, coding conventions, and top down design and implementation. The PSL provided extensive data collection and reporting capabilities for use by management in making timely assessments of status. This complement of software engineering techniques will be utilized during the operation and maintenance phase of the PAVE PAWS system. Thus, software maintenance personnel will utilize the tools and methods employed during development.

The PAVE PAWS Modern Programming Data Collection System effort described in this report was initiated as part of an effort to determine the utility and effectiveness of software engineering technology as applied

to large system implementations. Furthermore, the PAVE PAWS programming environment was examined to obtain data on PSL software management functions and how the PSL reporting function affected management visibility into the software development process. A combination of manual and automated methods were used for the data collection. Manual data collection forms were used to characterize the programming environment and a software module was added to the PSL which gathered error and change data and produced summarizations of the change activity.

The data collection effort described herein has been supplemented by a technology assessment of the tools and methods used. The modern programming techniques and development tools won widespread acceptance by programmers and managers alike. Although the technology does not, in and of itself, guarantee success it must be credited with establishing an environment to support project success and the early identification of real or potential problems.

This report supports ongoing efforts under RADC technical program objectives under the Software Cost Reduction thrust of TPO 5, C^3 System Availability. The conclusions and recommendations contained in the report and the data obtained under this effort will be utilized by efforts in the Software Engineering Tools and Methods area. The report should be of significant value to all personnel involved in system acquisition and software development and the application of modern programming techniques.

Deane F. Bergstrom

DEANE F. BERGSTROM
Project Engineer

1.0 BACKGROUND AND INTRODUCTION

The PAVE PAWS system acquisition is a fixed-price acquisition by the Electronics Systems Division (ESD) of the Air Force to Raytheon's Equipment System Division requiring system design, development, and integration leading to Initial Operating Capability (IOC) within three years of contract award. It includes several different types of software system development, among them -

a. A real-time early warning system.

b. A real-time simulation system.

c. A non-real-time simulation scenario generator.

d. A non-real-time data reduction system.

This section describes the tactical system, the software development technologies required, and the allocation of system requirements to Computer Program Configuration Items (CPCIs).

1.1 PAVE PAWS System Description. The PAVE PAWS is a fixed base Phased Array Warning System utilized for the detection and attack characterization of Submarine Launched Ballistic Missiles (SLBM's) which penetrate the radar coverage. It consists of two Phased Array Warning Sensors located at Otis AFB, Mass. and Beale AFB, Calif. The primary mission of PAVE PAWS includes SLBM detection and tracking in order to provide the NORAD Cheyenne Mountain Complex (NCMC) with credible warning of SLBM attacks, including estimation of Launch and Impact (L&I) points, and times of L&I. As a secondary mission the PAVE PAWS supports the USAF SPACETRACK System with Earth Satellite Vehicle (ESV) surveillance, tracking, and data collection as requested by NCMC. SPACETRACK functions include:

a. Maintenance of a catalog of known ESVs.

b. Detection, recognition, and data reporting (either cross-section or position data) for ESVs specified by NCMC or by local system operators.

c. Detection, tracking, and data reporting (cross-section, position, and orbital element set data) for unknown ESVs.

Message communication, both to and from NCMC/SAC/NMCC/ANMCC, is performed in accordance with the American National Standard for Advanced Data Communication Control Procedures (ADCCP) over Government data links. The system also includes six display consoles which are used for Systems Operations, Monitoring and Control, Missile Warning Operations, SPACETRACK Operations, Training, and Maintenance Control. Over thirty different display formats are independently selectable at the display consoles in order to provide complete flexibility in monitoring and controlling the system. Because the PAVE PAWS is an on-line system which is intended to be operational 7 days per week, 52 weeks per year, the data processing system contains redundant hardware throughout. In the event of a hardware or software fault, hardware is automatically reconfigured to eliminate the fault and resume the primary mission within 8 seconds. The data processor (duplex CDC CYBER 174's) communicates with one of two MODCOMP mini-computer which interface directly with the radar hardware (signal processor, et al). The hardware configuration is shown in Figure 1. The MODCOMP computer controls and directs reconfiguration of the radar hardware, the real-time system resident in the on-line CYBER controls MODCOMP reconfiguration, and the PAVE PAWS Operating System (CYBER) directs CYBER reconfiguration.

In addition to the software to perform the primary and secondary missions of PAVE PAWS, the system includes a simulation facility capable of operating concurrently with the operational software and providing the full range of mission, threat, communications, and radar stimuli to that software. Object trajectories, radar cross sections, launch and impact points, communications messages, radar environmental effects, and event timing can be simulated under user specification. The system also records real-time data pertinent to the performance of the primary and secondary missions and provides data reduction capabilities for a wide variety of recording formats.

The structuring of these requirements into Computer Program Configuration Items (CPCIs) and Computer Program Configuration Groups (CPCGs) is discussed in Section 1.3.

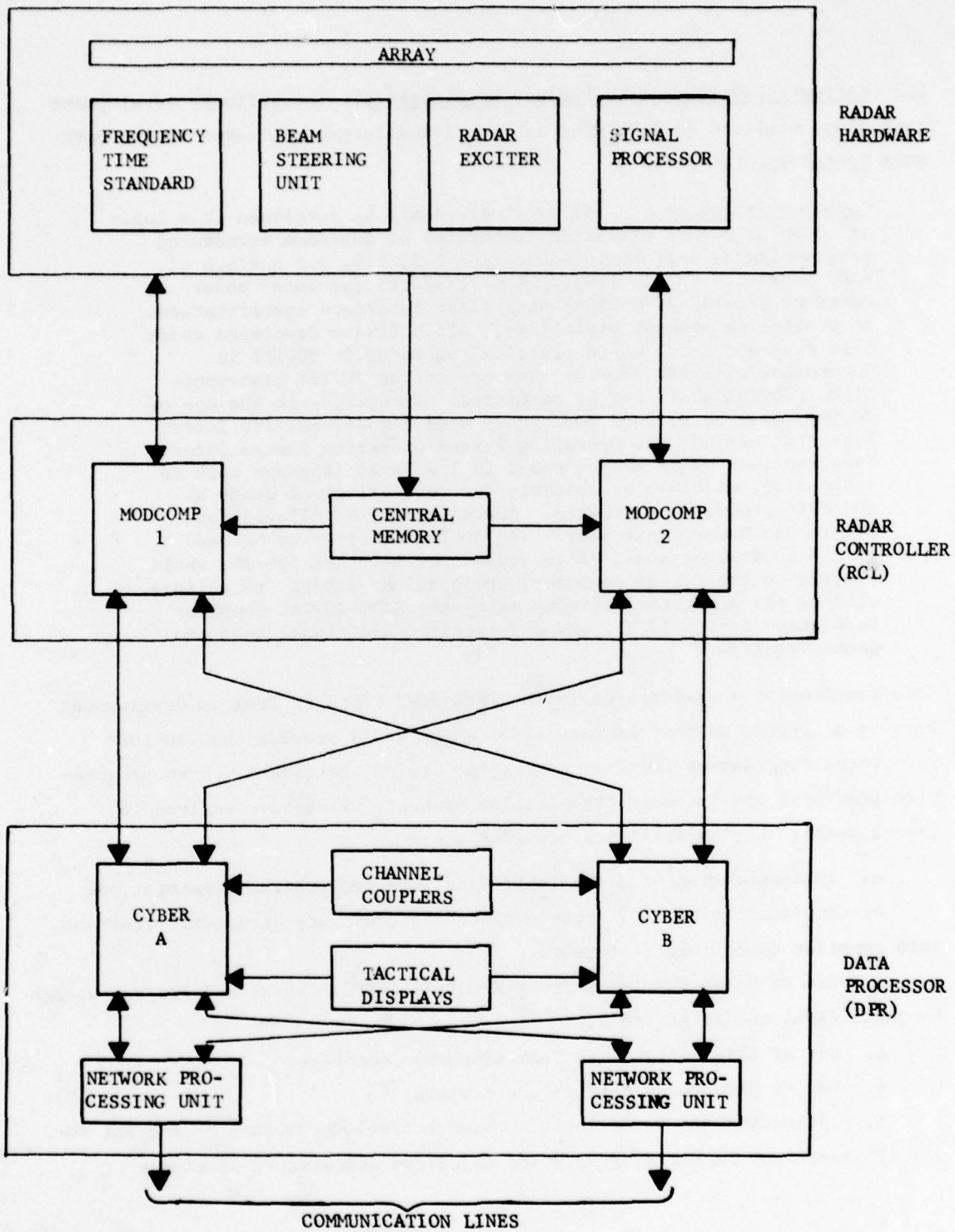


Figure 1. PAVE PAWS System Block Diagram

1.2 Software Development Technology Requirements. The software development technology utilized on PAVE PAWS was specified in general terms in the PAVE PAWS System Specification:

> Computer Programming. "All software shall be developed in a logical modular manner utilizing techniques of top-down structured programming as defined in Subsection 2.2, 2.4, 3.2 and 4.3 of RADC TR-74-300 Vol 1, Programming Standards (produced under Contract #F30602-74-C-0186) with clear interface specifications to provide management visibility. All software developed under this contract shall where practical be coded in JOVIAL in accordance with AFR 300-10. The use of the JOVIAL statements DIRECT/JOVIAL shall not be permitted. Exceptions in the use of JOVIAL shall be allowed for highly used algorithms, I/O Interface routines and the Operating System/Operating System Interface routines which may be coded in low level language such as micro code, machine, or assembly for more efficient usage of the data processing hardware. FORTRAN shall be allowed for use in the Radar Controller. The JOVIAL compiler to be used by the contractor shall be in accordance with AFM 100-24, shall operate on the system computer, and shall be subject to validation by the procuring activity using the RADC JOVIAL Compiler Validation System (JCVS) and any specific additional test programs required."

This requirement was addressed in the PAVE PAWS Computer Program Development Plan by a Program Support Library (PSL) which would provide the Top-Down Structured Programming facility and by the use of additional modern programming practices and software organization concepts which have evolved in recent years. Key capabilities provided are:

a. Implementation of a PSL to provide Top-Down program segmentation.

b. Implementation of a "pre-compiler" to translate Structured Programs into compiler compatible statements.

c. Use of Hierarchy Input-Process-Output (HIPO) charts and Program Design Language (PDL) as design tools.

d. Use of Chief-Programmer Team/Librarian concepts.

e. Use of Structured Design/Code Reviews.

f. Collection and reporting of software development data by the PSL for use by management in making timely and objective assessments of status.

g. Creation of a Test organization separate from the software development group responsible for developing all test documentation and for conducting the tests.

h. Organizational separation of the group responsible for developing the Quality Assurance Program, including the establishment of project-wide procedures, implementation of a Trouble Report system, and providing regular assessments of status and forecasts for management consideration and action, from the software development group within each implementing organization (IBM, CDC, Raytheon).

The technical scope and content of the PAVE PAWS PSL is discussed in Section 3. Section 5, the Technology Assessment, addresses key elements of the PSL together with the other procedural and organizational practices mentioned above.

1.3 Software Hierarchy (CPCI/CPCG Formulation). The allocation of system requirements to individual Computer Program Configuration Items (CPCIs) is an important function because from that point forward each CPCI will be managed with a certain degree of autonomy. The term "managed" in this context includes -

a. estimating and planning the effort involved,
b. allocating resources,
c. assessing and reporting status,
d. financial management and reporting, and
e. the resolution of technical problems.

Clearly it is important that these functions provide control and visibility below the total system level, but the danger of subdividing too much is that "all the pieces work but the system doesn't." A number of guidelines were developed for defining CPCIs on PAVE PAWS in order to establish an effective subdivision of the total software effort:

f. CPCI responsibility should not cross corporate boundaries.
g. CPCIs should not cross computer boundaries.
h. Software systems which are executed separately should be separate CPCIs.

The resultant CPCI definitions are presented in Figure 2.

CPCI	Title	Corp.	Comp.	Size (Lines)
1	PAVE PAWS Operating System	CDC	CYBER	N/A
2	Tactical Software	IBM	CYBER	139K
3	Simulation Software	IBM	CYBER	29K
4	Support Software	IBM	CYBER	16K
5	Data Reduction	IBM	CYBER	27K
6	Radar Control Software	RAYTHEON	MODCOMP	N/A
7	Signal Processor Software	RAYTHEON	Sig. Proc	N/A

Figure 2. PAVE PAWS CPCI Breakout

Below the CPCI level, software is next broken down into Computer Program Configuration Groups (CPCGs) and Computer Program Components (CPCs). CPCGs are generally structured along major functional lines within a CPCI while CPCs represent individual programs. This structuring of the software is important because it forms the basis for allocating system requirements to software, identifying interface control definitions, subdividing design and development responsibilities, and making personnel assignments. In short, a well understood software structure allows a software project to be effectively managed.

The CPCG structure for CPCI 2 is shown graphically in Figure 3. In this figure each CPCG is scaled to show its relative size (source cards).

1.3.1 Real Time Monitor (RTM). The Real Time Monitor (RTM) acts as the single interface between the PAVE PAWS Operating System (PPOS) and the tactical or mission software of CPCI 2. It performs interrupt handling, cyclic and demand task schedulings, task dispatching in accordance with system priorities, Input/Output resource management, and dynamic storage management.

1.3.2 Mission Control (MCTL). Mission Control performs the high level control functions of CPCI 2, including initialization, reconfiguration, and termination. It also provides disk file, recording, and errorlog services, and checkpointing of tactical data in support of system reconfiguration.

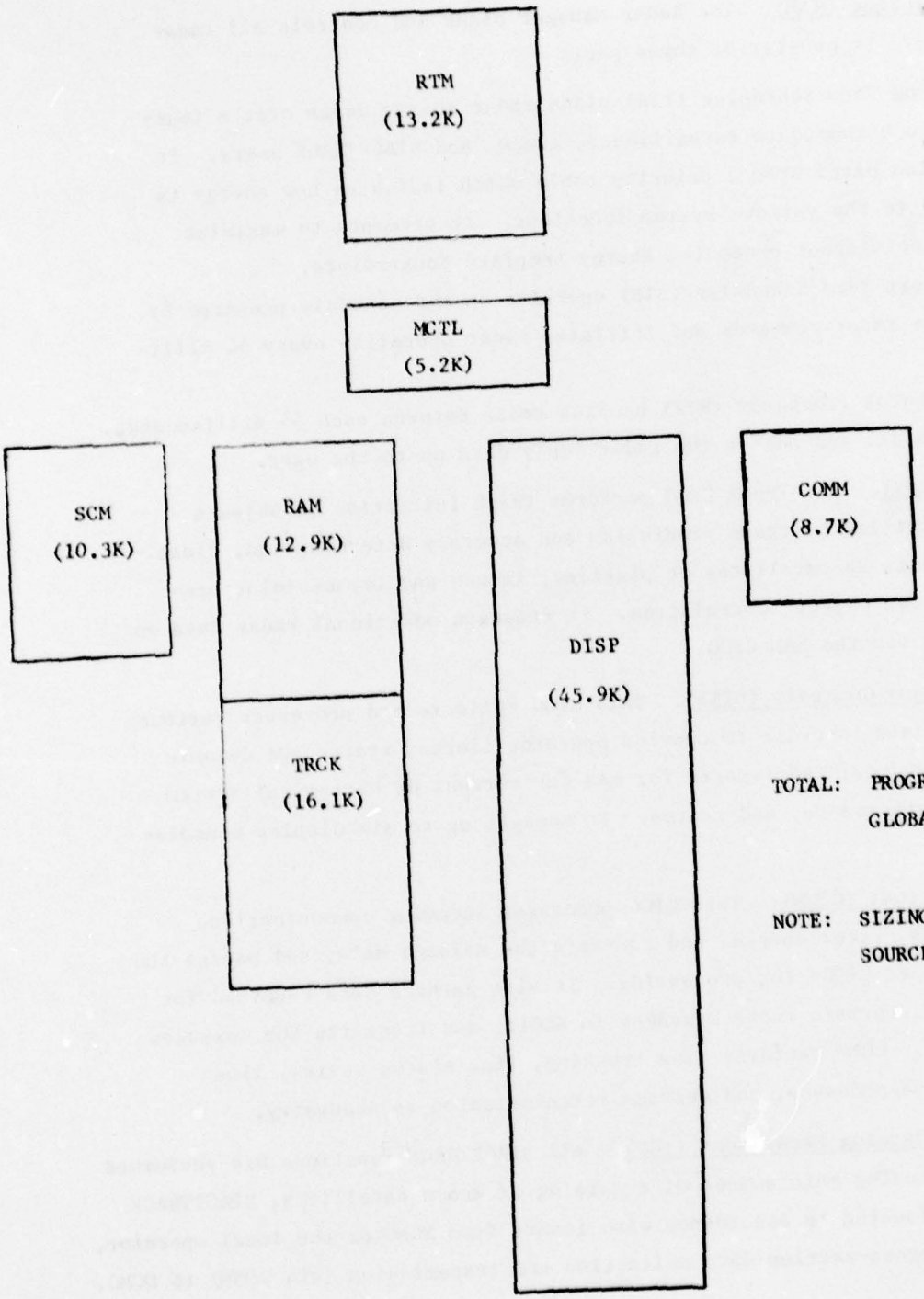


Figure 3. CPCG Structure for CPCI 2

1.3.3 Radar Manager (RAM). The Radar Manager plans and controls all radar subsystem usage. It consist of three parts -

1. The Long Term Scheduler (LTS) plans radar energy usage over a four-second period to accommodate surveillance, track, and SPACETRACK users. It develops the plan based upon a priority table which indicates how energy is to be allocated to the various system functions. It attempts to maximize radar utilization without exceeding energy template constraints.

2. The Short Term Scheduler (STS) operates on the schedule prepared by LTS, formats the radar commands and initiates radar operation every 54 milliseconds.

3. The Returns Processor (RTP) handles radar returns each 54 milliseconds, checks radar status, and passes the radar reply data on to the user.

1.3.4 Track (TRCK). The Track CPCG performs track initiation on objects detected in surveillance, track prediction and accuracy determination, classification of objects as satellites or missiles, launch and impact point prediction, and "known object" correlation. It requests additional radar data on objects in track via the RAM CPCG.

1.3.5 Displays and Controls (DISP). This CPCG collects and processes various types of system data in order to provide operator alerts, static and dynamic display images, and printed reports for man for current or historical system events, system performance, and status. It manages up to six display consoles independently.

1.3.6 Communications (COMM). This CPCG processes incoming communications messages, unblocks, error checks, and converts the message data, and passes the messages on to other CPCGs for processing. It also gathers data required for outgoing messages, formats those messages in ASCII, and transmits the messages to external sites. COMM performs line trunking, line status review, line error statistics maintenance, and message retransmission as necessary.

1.3.7 Satellite Catalog Management (SCM). All SPACETRACK functions are performed in this CPCG, including maintenance of a catalog of known satellites, SPACETRACK data collection planning in accordance with inputs from NCMC or the local operator, and position and cross-section data collection and transmission (via COMM) to NCMC.

2.0 CONTRACT FOR DATA COLLECTION

Realizing that the PAVE PAWS software development effort represented a unique opportunity to collect information and experience relative to "modern programming technology", Raytheon/IBM submitted an unsolicited proposal to Rome Air Development Center (RADC) proposing that such data be collected for CPCI's 2 through 5 and provided to RADC for their use in on-going technology evaluation studies. This contract was awarded in August 1977.

2.1 Contract Purpose. The purpose of the Data Collection contract was to validate the special tools used, to provide guidance on programming environments for large system acquisitions, and to provide insights into new experiences in software engineering using modern programming tools and methods. Specific areas of interest on PAVE PAWS were:

a. Use of a comprehensive Program Support Library system (the PAVE PAWS PSL).

b. Structured coding, including the use of language precompilers.

c. Top-down design and implementation.

d. Use of Program Design Language (PDL).

e. The use of transaction data collection and reporting to management.

f. Chief-Programmer Team Operations.

g. Use of a Programmer Librarian.

h. Effective programming standards and conventions.

2.2 Contract Scope. The intent of the Data Collection effort was to provide data which characterized the nature and environment of the software development activity together with information about the reasons underlying software change. This would allow ongoing software technology studies at RADC to correlate software change activities with project characteristics such as the size, complexity, and schedule of the project, the type of contract, the programming technology utilized, the management organization and methodology, the programming language utilized, the data processor availability and capacity, the system documentation structure and availability, etc. The collection of this data was effected in three ways:

a. Manual collection of project and personnel characteristics.

b. Automatic collection of software change data by the PAVE PAWS PSL.

c. Automatic recording and summarization of software change activity as part of a project-wide Trouble Report/Change Request (TR/CR) system. Because the bulk of the software design and development had been completed by the time of contract award, the "automatic" collection of data was augmented by a one-time manual reconstruction of the existing TR/CR data base.

2.2.1 Manual Data Collection. The following types of data were provided through the completion of forms by project personnel:

a. General Contract/Project Summary (see Appendix I). This form provides general information about the size of the project (cost, people, software, and documentation) together with a high level technical description of the project.

b. Management Methodology Summary (see Appendix II). This identifies management procedures utilized, the schedule for PDR's and CDR's and an enumeration of the AF and Military Standards which apply.

c. Design and Processor Summary (see Appendix III). This identifies the data processor configuration, the programming languages used, the standards followed, and the software technology utilized.

d. Chief Programmer Team Profiles (see Appendix IV). These forms characterize the educational and work experiences of each of the teams on PAVE PAWS.

2.2.2 Automatic Data Collection. Changes were made to two existing PAVE PAWS systems in order to automate the collection and reporting of software change data. The first of these was an extension to the PSL to require that programmers specify a "reason code" for each program compilation. The second was a change to the Trouble Report/Change Request system which similarly required the specification of a "reason code" at the time the TR or CR was closed. It should be noted that the PSL data will include programming effort which does not fall under the TR/CR system and that one TR (or CR) may result in many PSL operations before the problem is solved. Thus the two systems collect data which overlaps but is in no way the same. These systems and the data they collect are further described in Section 4.0.

3.0 PAVE PAWS PROGRAMMING ENVIRONMENT

The PAVE PAWS Program Support Library (PSL) is a programming system specifically designed to support and enforce Top-Down and Structured Programming technologies. This requires a program storage and maintenance capability which is oriented toward a high degree of program segmentation and a precompiler which has the effect of extending the commercial JOVIAL, COMPASS, and IFTRAN languages to include the necessary structured forms. Additionally, the PSL has been designed to accommodate a structured Program Design Language (PDL). Although similar to most compiler languages, PDL is completely unconstrained in syntax, thus allowing natural English-like description of program design. This section describes the PSL implemented and utilized on PAVE PAWS. A subjective evaluation of its most effective features is provided in Section 5.

3.1 Top-Down Programming/Segmentation. Top-Down programming is based upon a technique of designing (and implementing) software by specifying the top level functions first. The details of each of those functions and the specification of additional subfunctions are then developed through successive iterations until the entire problem is fully developed. Throughout this process the amount of design (or code) which is being developed is purposely kept fairly small in order to allow it to be dealt with effectively. This can only be accomplished by referring to total functions or sub-functions as "black box" modules with known input and output requirements. This modularization is reflected in the PSL through program segmentation. A segment of program code can identify a needed function by using an INCLUDE statement:

```
INCLUDE function name
```

This named function can then be dealt with independently, and it may itself utilize INCLUDE statements to identify and define even lower level functions. In this way a program is developed as a set of single page segments which fit together in a program structure or hierarchy. The PAVE PAWS PSL is designed to

handle such highly segmented programs. The Top-Down aspect of software development is enforced by identifying each segment placed in the library as either a top-segment (i.e., the top-level of an independently compiled program) or as an INCLUDE'd segment (one which is simply a lower-level part of some program). As top-level segments are entered into the library and INCLUDE statements are encountered, stubs are generated to act as position holders until real-code is provided. A program stub identifies the need for code to perform the named function, it reserves the name for that function, and since it is part of some already existing program, it specifies the implementation language for that function. The Top-Down ordering of software development is enforced by requiring that INCLUDE'd segments cannot be added into the PSL library unless they are replacing a stub. In addition, since stubs represent unimplemented software segments, the number of stubs in a CPCG or a program can be used as a measure of status or progress. Section 3.6 describes the PSL tools available for dealing with these program segments.

3.2 Structured Coding. Structured Coding requires the use of a standard set of program control statements and at the same time precludes the use of explicit branching statements. In order to provide the standard set of control statements for JOVIAL, COMPASS, IFTRAN and PDL programmers, the PSL includes a pre-compiler which accepts the structured source statements and converts them into traditional control forms which are processed by the appropriate compiler. Figures 4 through 7 show both the logical form and the coded form of each of the PAVE PAWS standard control forms. It should be noted here that the requirement to provide a separate statement to end each of the forms provides an ideal closure mechanism for the generation of indented listings which are discussed in the next section.

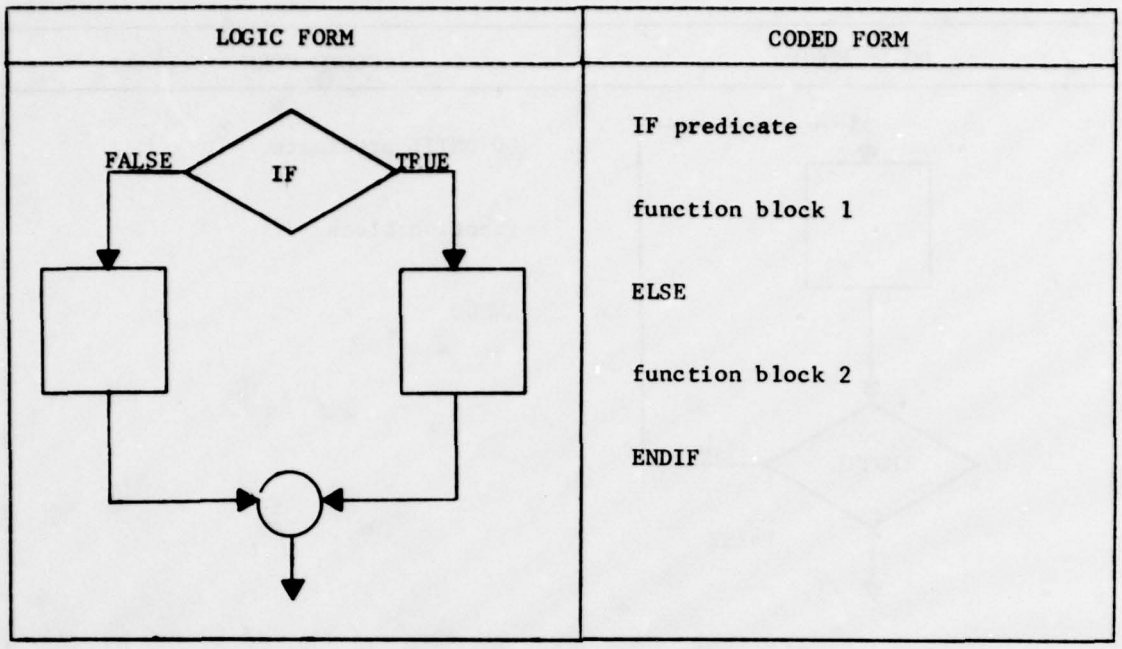


Figure 4. IF_THEN_ELSE Logic Form

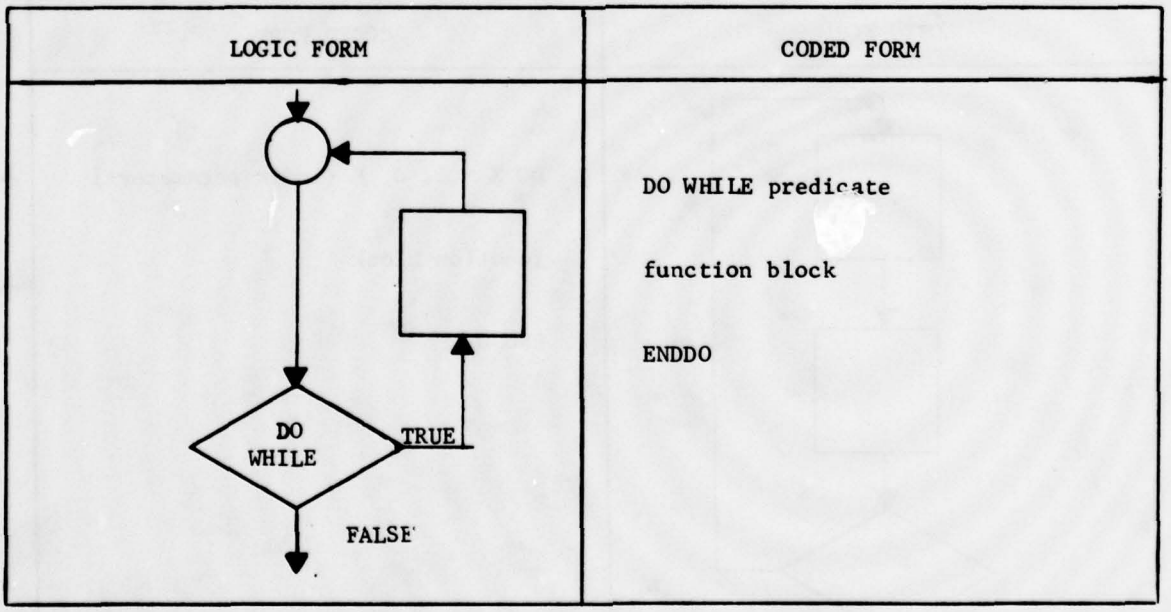


Figure 5a. DO WHILE Logic Form

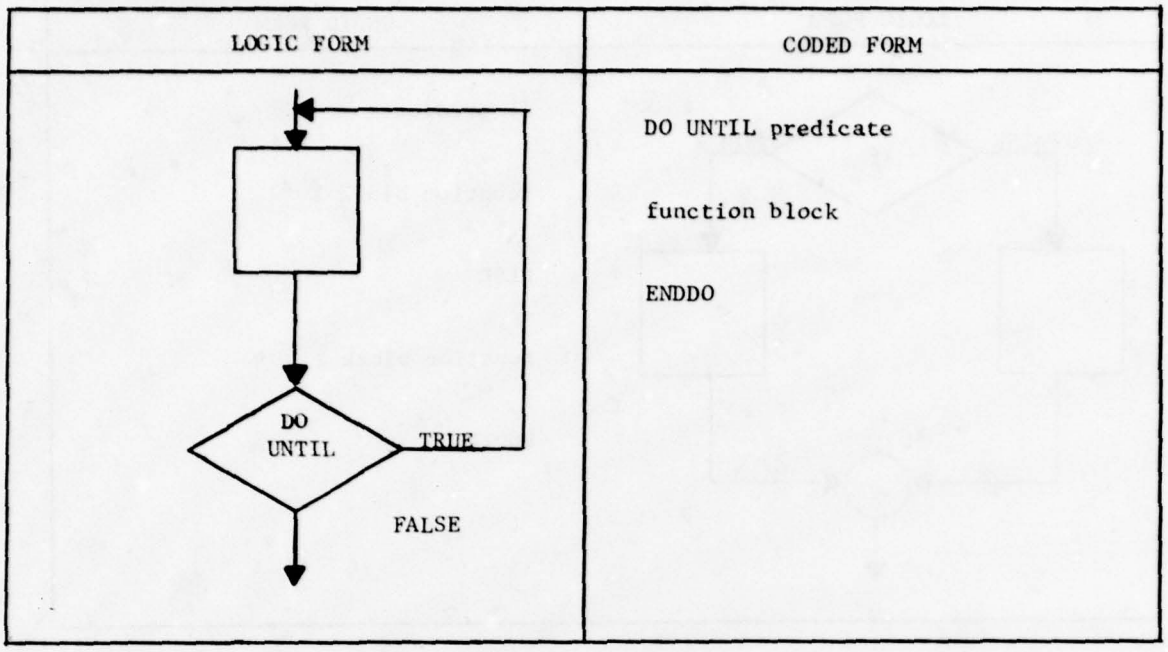


Figure 5b. DO UNTIL Logic Form

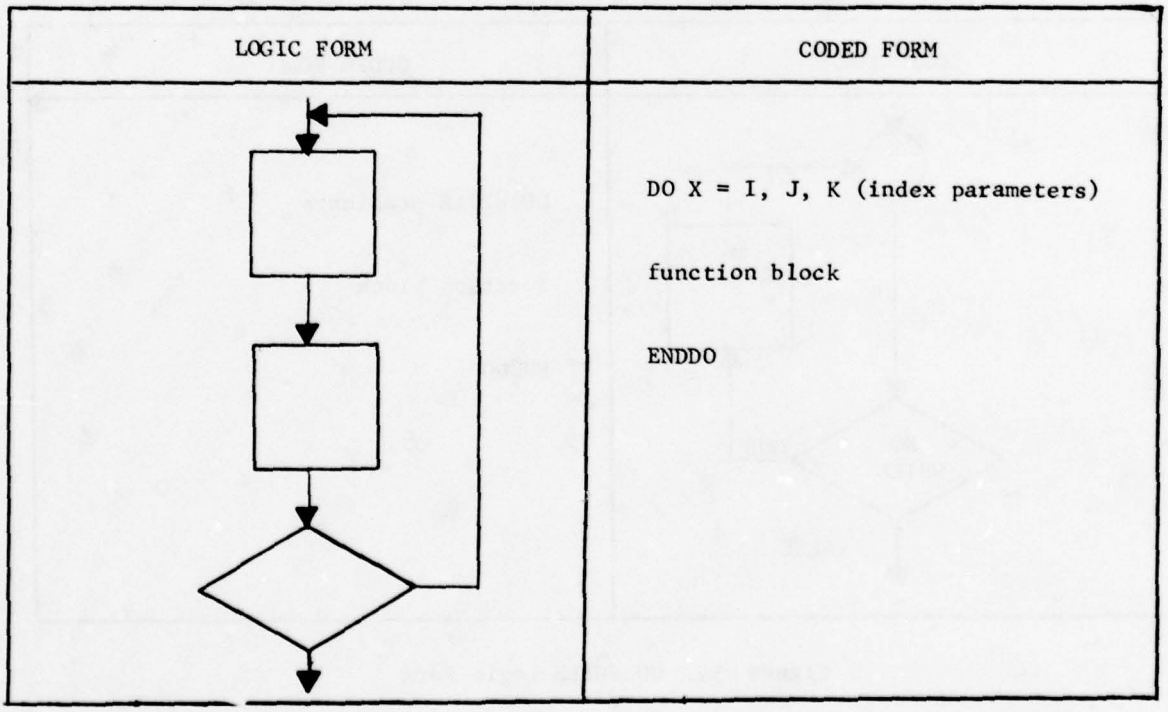


Figure 6 - DO Logic Form (Indexing)

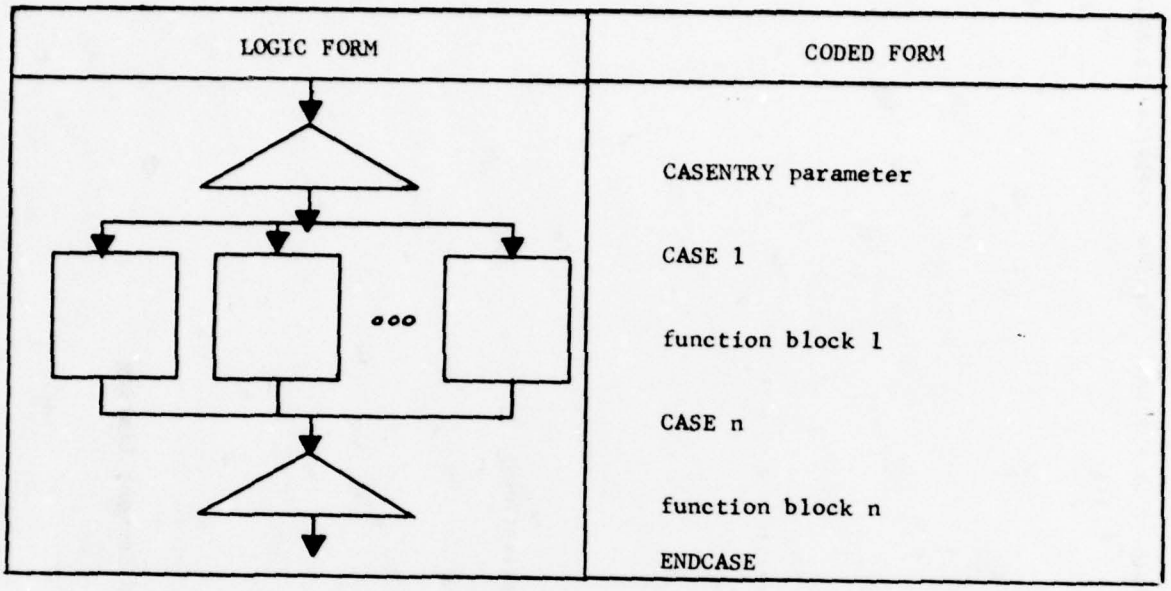


Figure 7 - CASENTRY Logic Form

3.3 Indented Listings. One of the principal advantages accruing from top-down structured programming is the ability to generate program listings which physically identify logic structure by pairing the statements which open and close a logic form and indenting all intervening statements. Figure 8 is illustrative of an indented segment listing as prepared by the PSL. Figure 8a is an explanation of the data displayed in Figure 8.

```
79/03/02  16.18.52  PAVE PAWS VERSION-79/02/28.  SEGMENT = PSL.SSDSAR.PURGE.ELEMENT                    LVL=TST  EDN=  9

      LANGUAGE=JOV   TYPE=INCL  VERSION=A0    CREATED  77/01/10  15.36.40 BY PH8DAD    CHANGED  78/09/14  12.28.23 BY I8MFIX

          LIST BY SEGMENT   FOR PSL.SSDSAR.PURGE.ELEMENT                    PPG

 1 SEGMENT                                                                                                    1
 2 .   CALL =PSL.SSDSAR.GET.CPCG.PAGE $                                                                      2
 3 .   IF STATUS=FLAG EQ 0  $                                                                               3
 4 .   .   DO A = 0:1:NENT(CPCG=PAGE) - 1  $                                                                4
 5 .   .   .   IF CTL=UNIT=LONGNAME($0$) EQ CPCG=UNIT=LONGNAME($A$)  $                                       5
 6 .   .   .   .   IF CTL=REQUEST=LEVEL($0$) EQ CPCG=UNIT=LEVEL($A$)  $                                     6
 7 .   .   .   .   .   STATUS=FLAG = CPCG=UNIT=LEVEL($A$)  $                                                7
 8 .   .   .   .   .   ITEM DATA=KEY I 48 U $                                                              8
 9 .   .   .   .   .   DATA=KEY = 0 $                                                                      9
10 .   .   .   .   .   IF  CPCG=UNIT=REAL=STUB ($A$)  EQ  V(REAL)  $                                       10
11 .   .   .   .   .   .   DATA=KEY = CPCG=UNIT=POINTER($A$) $                                             11
12 .   .   .   .   .   ENDIF                                                                               12
13 .   .   .   .   .   IF NENT(CPCG=PAGE) GR A + 1  $                                                     13
14 .   .   .   .   .   .   DO B = A+1:NENT(CPCG=PAGE) - 1  $                                               14
15 .   .   .   .   .   .   .   ENT(CPCG=PAGE($B$)) = ENT(CPCG=PAGE($B+1$))  $                              15
16 .   .   .   .   .   .   ENDDO                                                                           16
17 .   .   .   .   .   ENDIF                                                                               17
18 .   .   .   .   .   NENT(CPCG=PAGE) = NENT(CPCG=PAGE) - 1  $                                           18
19 .   .   .   .   .   A = NENT(CPCG=PAGE) + 1  $                                                         19
20 .   .   .   .   .   CALL PSL.SSDSAR.PURGE.CPCG.PAGE $                                                  20
21 .   .   .   .   .   IF DATA=KEY NO 0 $                                                                 21
22 .   .   .   .   .   .   PERFRM(5,DATA=KEY) $  **DELETE DATA**                                          22
23 .   .   .   .   .   ENDIF                                                                               23
24 .   .   .   .   ENDIF                                                                                   24
25 .   .   .   ELSE                                                                                        25
26 .   .   .   .   UNIT=LONGNAME = CPCG=UNIT=LONGNAME($A$)  $                                             26
27 .   .   .   .   LNCOMP(UNIT=LONGNAME,LOC(PSL=CONTROL=BLOCK),COMPARE=RETURN)  $                         27
28 .   .   .   .   IF COMPARE=RETURN GR 0  $                                                             28
29 .   .   .   .   .   A = NENT(CPCG=PAGE)  $                                                            29
30 .   .   .   .   .   STATUS=FLAG = 0  $                                                                30
31 .   .   .   .   ENDIF                                                                                   31
32 .   .   .   ENDIF                                                                                       32
33 .   .   ENDDO                                                                                          33
34 .   ELSE                                                                                               34
35 .   .   STATUS=FLAG = 0  $                                                                            35
36 .   ENDIF                                                                                              36
37 ENDSEG                                                                                                  37
```

Figure 8. Example of Indented Segment Listing

Top Line - Date and Time of computer run producing this listing
- Version ID (date) of the PSL
- Name of the segment being listed
- Library level at which the segment was found
- Edition number of the segment (incremented for each change)

Second Line - Segment Language - JOV = JOVIAL
- PDL = PDL
- COMP = COMPASS
- IFTR = IFTRAN
- LEL = LEL (loader statements)

- Segment Type - INCL = INCLUDE
- MAIN = MAIN PROGRAM
- SUBR = SUBROUTINE
- LOCL = LOCAL PROCEDURE
- *COMP = COMPOOL*

- Segment Version (established by the user)
- Date, Time, and User ID when segment was created
- Date, Time, and User ID when segment was last changed

Third Line - Request type and library level
(LIST PROGRAM or LIST SEGMENT)
(For the example shown, a segment listing was requested
for PSL.DATA.STORAGE.AND.RETRIEVAL at the PRG level;
this particular segment was drawn down from the TST level,
as indicated on Line One.)

Left, Right Margins - Line sequence numbers used for directing modifications

Body of Listing - Card images left justified then indented to show logical structure. (Periods are used as a visual connector for indentation.)

Bottom Line - Repeat of Top Line

Figure 8a: Explanatory Notes for Figure 8

3.4 Hierarchical Library. The PAVE PAWS PSL is designed to support an orderly and well controlled progression of software from a development environment through integration and test into a delivered status. This is implemented as a multi-level program support library or hierarchy. Software segments are entered into the library using a user-specified name (up to 40 characters long) at a user specified level. (By convention, the first four characters of each software element name represent the Computer Program Component Group (CPCG) to which it belongs; the remainder of the 40 character name may be constructed of multiple alphanumeric syllables separated by periods.) Since each level of the library is separate and distinct from all other levels, the same software element may appear in the library at several different levels. Thus, to completely identify an item in the library it is necessary to specify both the name and level. This provides a simple mechansim for parallelism in development, error correction, and version modification. Within the PSL seven library levels are defined in a progressive hierarchy. These levels are shown in Figure 9, starting with the highest.

Level	Usage Convention
DEL	software which is in the field
FRZ	software which has been qualified
TST	software undergoing qualification test
FIX	software corrections for TST level
INT	software undergoing integration test
CPT	software undergoing group test
PRG	software under development/unit test

Figure 9. PSL Library Levels

Basic to the PSL level hierarchy are the concepts of control level and the migration of program elements from one level to another. A program element is ready to change control level when it has satisfied a predefined qualification criteria and is to be placed under more stringent change control.

This is effected within the PSL by use of an XMIT directive (see Section 3.6). All segments of a program which is being XMIT'ed will be moved to the specified level. In order to facilitate changes to segments once they have been XMIT'ed from one library level to another, the PSL includes a feature called "automatic drawdown". This feature allows library operations to be addressed to a specific library level and if the element does not exist at that level, successively higher levels will be searched until the element is found. Once found, it will be treated as if it were found at the originally requested level. This is based upon the upward migration of software through library levels and the recognition that all elements above the requested level have of necessity already satisfied the functional benchmark associated with that level.

3.5 Authorization Checking in PSL. The hierarchical nature of the PSL library system readily lends itself to the systematic application of change control procedures. Since the migration of programs from level to level requires that successively more stringent benchmarks have been satisfied, the software stability (and the corresponding authorization required to effect change) continually increases from the lowest level to the highest. This is addressed in the PSL through an authorization verification scheme which recognizes users (by an input ID) and restricts the operations and the library levels which they may use. The scheme is based upon a combination of user identity and organization and it disallows:

a. Operations on software which is not in the province of that organization.

b. Transactions at library levels at which the user is not authorized and,

c. Execution of special PSL verbs for which the user is not authorized.

Among other things, implementation of this authorization check may prevent a programmer in one department from changing code belonging to another department, inhibit the Development organization from making changes to software which has been delivered to Test, prevent Test from accessing any software which has not been delivered to them, and disallow any source change activity (ADD, MODIFY) above the INT level of the library.

3.6 PSL Directives. This section provides a brief description of each of the PSL directives.

3.6.1 ADD. The ADD directive is used to add a new segment of code to the PSL library. It must specify the segment longname and the level at which the segment is to be added, in addition to a number of other items which define the segment. Following a successful ADD an indented segment list is produced automatically.

3.6.2 MODIFY. The MODIFY directive is used to make updates to code segments which are already in the PSL library. It must specify the segment longname, level, and edition number. The MODIFY directive is immediately followed by sub-directives which describe the changes to be made. Following a successful MODIFY operation the segment edition is incremented, the updated segment is written into the requested library level, and an indented segment list is generated.

3.6.3 COMPILE. The COMPILE directive initiates the pre-compiler of the PSL which performs source segment merging and forms translation before invoking the appropriate commercial compiler (JOVIAL, COMPASS, or IFTRAN). At the completion of this step the program statistics are updated in the library and a compilation listing is printed.

3.6.4 LOAD. This directive specifies that a user program consisting of NOS and LOADER CONTROL cards be precompiled and then executed. The directive must specify the longname of the user program and the library level. This function is identical to the COMPILE directive with the exception that the pre-compiled program will be executed rather than compiled.

3.6.5 COPY. The COPY directive specifies that a code segment at a specific level be copied to another segment and level. The names of the "from" and "to" segments may be different.

3.6.6 XMIT. This directive is used to deliver programs from one level to another. It specifies a program name (top-segment name), a "from" level, and a "to" level. XMIT will use the drawdown feature of the PSL to construct

the entire source program hierarchy. It will then move all of those segments up to the specified "to" level. (Segments which were drawn down from that level or above are not moved unnecessarily, however.) At the same time a full set of source listings for the program will be printed.

3.6.7 LIST. The LIST directive is used to request an indented listing. It must specify either a SEGMENT list (one segment only), a PROGRAM list (the full set of segment listings for the specified program plus a hierarchy listing which shows the program structure), or a HIERARCHY list (which generates the program structure without any segment listings). During list processing a number of error conditions are tested and if detected the segment statistics will be updated appropriately. These conditions include:

a. source segment exceeds one page limit (56 lines - an F flag),

b. protocol errors due to improper coding of control forms (a P flag),

c. mixed language error if an INCLUDE'd segment is a different language (M flag)

d. branching error if explicit branch statements are detected (B flag),

e. COMPOOL access error if the stated ACCESS requirements do not match the design access (a C flag),

f. syntax errors (S flag).

The indentation of each segment listing shows the direct relationship between control forms. Each line also contains a line number for reference when making MODIFY's.

3.6.8 REPORT. The REPORT directive requests that summary data be extracted from the PSL library and prepared in report format. There are three different types of reports which may be selected - SEGMENT summary, PROGRAM summary, and LIBRARY summary. (These reports are discussed in Section 3.7).

3.6.9 PURGE. This directive is used to delete segments from the library. It does not use the drawdown feature.

3.6.10 PUNCH. This directive provides a mechanism for getting card image representation of a segment out of the PSL. It is a convenient mechanism for maintaining procedure or data files.

3.6.11 CHECKPOINT. This directive causes PSL to create a checkpoint file containing every segment in the PSL.

3.6.12 RESTORE. The RESTORE directive allows the user to restore elements to the PSL library from a checkpoint file.

3.7 Management Statistics Reporting. The PSL maintains statistical data for each segment and each program in the library. Segment data is derived from the user specified values when the segment was ADD'ed (longname, shortname, language, segment type, version) or computed automatically by the PSL (creation date, date and time of last change, number of lines, ID of the user making the last change, etc.). Program data, which is associated with the top segment of each program but is distinct from its segment statistics, is computed at the time the program is either LIST'ed or COMPILE'd. It includes the date and time of the most recent segment change, the total number of segments, lines of code, and stubs in the program, the date and time at which the program was compiled, and the program object size. The REPORT directive may be used to prepare tabular summaries of either SEGMENT statistics or program statistics, examples of which are in Figures 10 and 11. (Descriptions of the contents of these reports are given in Figures 10a and 11a.) These reports are subdivided by CPCG and then by library level. Each level also contains totals as shown at the bottom of these examples.

In addition to the SEGMENT and PROGRAM REPORTS mentioned above, a LIBRARY report may be requested. This report provides very basic summary data as shown in Figure 12 as well as the Code Progression/Durability report shown in Figure 13. This latter report addresses "effective code" in the PSL library by eliminating the double-accounting which arises from multiple versions of the same segment appearing at different levels and simultaneously accommodating the drawdown feature for code which exists at a higher level. The Code Progression part of the report, which is organized as a CPCG/level matrix, indicates how much effective code exists (using drawdown as necessary) at each level of the library. Thus code (segments) which exist at the INT level of the library, "effectively" exist at the PRG and CPT levels as well. Since each of the library levels represents some sort of testing benchmark, this report allows management to answer questions like "How much code has reached functional test?", "How much code has been integrated?," "How much code has been written?"

UNIT NAME	SHRTNM	LANG	UNIT TYPE	DATE CREATED	NET SZ	GRS SZ	DATE/TIME CHNGED	VN	EDN	TOT NBR CHG	NBR CHG VN	NBR LNS VN	OWNER	FLAGS	LAST PGR CHG
MREP.CARRIAGE.CONTROL.BLANK	SSSK01	JOV	LOCL	77/02/08	7	7	77/02/08 11.10.05	A0	0	0	0	0	PHBLAH		
MREP.CARRIAGE.MINUS	SSSK03	JOV	LOCL	77/02/08	7	7	77/02/08 11.10.05	A0	0	0	0	0	PHBLAH		
MREP.CONTROL		JOV	INCL	77/02/08	10	10	77/02/08 11.10.05	A0	0	0	0	0	PHBLAH		
MREP.DATA.INITIALIZATION		JOV	INCL	77/02/08	57	114	77/07/14 01.09.40	B0	1	4	2	13	PHBLAH	F	WBV
MREP.HEADING.SUMMARY.BY.LIBRARY	SSHLIB	JOV	LOCL	77/02/08	11	13	77/03/17 19.16.36	A0	1	1	1	3	PHBLAH		VDG
MREP.HEADING.SUMMARY.BY.PROGRAMS	SSHPRG	JOV	LOCL	77/02/08	13	23	77/05/23 13.28.37	B0	1	3	2	7	PHBLAH		WBV
MREP.HEADING.SUMMARY.BY.SEGMENTS	SSHSEG	JOV	LOCL	77/02/08	17	20	77/03/17 19.16.36	A0	1	1	1	0	PHBLAH		VDG
MREP.LIBRARY.INDEX.PROCESSOR	MREPLP	JOV	LOCL	77/02/08	50	109	77/07/21 12.17.45	B0	4	6	5	50	PHBLAH		WBV
MREP.LIBRARY.PAGE.FORMATTER	MREPLF	JOV	LOCL	77/02/08	34	48	77/05/05 14.05.38	B0	1	4	2	12	PHBLAH		RW1
MREP.LIBRARY.PROGRESSION.REPORT		JOV	INCL	77/04/13	22	24	77/07/21 12.17.45	B0	3	3	3	4	PHBVDG		WBV
MREP.LIBRARY.REPORT.GENERATOR	MREPLG	JOV	LOCL	77/02/08	17	28	77/04/14 13.55.13	A0	3	3	3	2	PHBLAH		VDG
MREP.MAIN	PSLRPT	JOV	SUBR	77/02/08	34	52	77/07/14 01.09.40	A0	3	3	3	4	PHBLAH		WBV
MREP.PROGRAM.DIRECTORY.PROCESSOR	MREPPP	JOV	LOCL	77/02/08	47	62	77/05/17 12.48.28	A0	6	6	6	17	PHBLAH		WBV
MREP.PROGRAM.PAGE.FORMATTER	MREPPF	JOV	LOCL	77/02/08	66	121	77/08/10 19.38.14	A0	9	9	9	52	PHBLAH	F	WBV
MREP.PROGRAM.REPORT.GENERATOR	MREPPR	JOV	LOCL	77/02/08	45	103	77/06/11 11.06.33	A0	7	7	7	39	PHBLAH		WBV
MREP.REQUEST.VALIDATION		JOV	INCL	77/02/08	42	92	77/06/11 11.06.33	A0	3	3	3	45	PHBLAH		WBV
MREP.SEGMENT.DIRECTORY.PROCESSOR	MREPSP	JOV	LOCL	77/02/08	46	60	77/05/16 12.04.28	A0	6	6	6	16	PHBLAH		WBV
MREP.SEGMENT.LINE.WRITER		JOV	INCL	77/02/08	42	55	77/07/14 01.09.40	B0	3	6	4	2	PHBLAH		WBV
MREP.SEGMENT.PAGE.FORMATTER	MREPSF	JOV	LOCL	77/02/08	42	74	77/08/26 11.23.22	A0	5	5	5	6	PHBLAH		WBV
MREP.SEGMENT.REPORT.GENERATOR	MREPSG	JOV	LOCL	77/02/08	46	105	77/06/11 11.06.33	A0	7	7	7	39	PHBLAH		WBV
MREP.SIMPLE.ITEM		JOV	INCL	77/02/08	20	26	77/04/13 10.50.07	B0	0	4	1	3	PHBLAH		VDG
MREP.TOP.OF.PAGE.HEADER	HEAD	JOV	LOCL	77/02/08	20	22	77/04/14 13.55.13	B0	0	2	1	0	PHBLAH		VDG
MREP.TOTALS.SUMMARY.BY.PROGRAMS	SSTPRG	JOV	LOCL	77/02/08	14	28	77/05/05 16.37.22	A0	3	3	3	8	PHBLAH		RW1
MREP.TOTALS.SUMMARY.BY.SEGMENTS	SSTSEG	JOV	LOCL	77/02/08	15	33	77/05/06 11.46.34	A0	4	4	4	10	PHBLAH		VDG

TOTALS	TOTAL NUMBER SEGMENTS	NET SIZE	GROSS SIZE	TOTAL NUMBER CHANGES	TOTAL NBR CHANGES - VERSION	TOTAL NBR LINES - VERSION
	24	724	1236	90	78	332

Figure 10. SEGMENT Summary

Top Line - Date and Time of computer run producing this listing.
- Version ID (date) of the PSL
- Type of report requested
- CPCG for this page of the report
- Library Level for this page of the report

Tabular Data - Segment longname
- Segment shortname (for MAIN, SUBR, LOCL, and COMP types)
- Segment type - INCL = INCLUDE
  - MAIN = MAIN PROGRAM
  - SUBR = SUBROUTINE
  - LOCL = LOCAL PROCEDURE
  - COMP = COMPOOL
- Date segment was created
- Current number of lines in the segment
- Gross size of segment (includes all lines which have been deleted)
- Date and time segment was changed
- Segment Version (established by the user)
- Segment Edition (incremented for each change)
- Total number of times segment has been changed
- Number of changes made to the current version
- Number of lines (gross) for the current version
- User ID of the person who created the segment
- Special Flags - F = Segment exceeds one page
  - P = Protocol error
  - S = Syntax error
  - B = Branching Statements
  - M = Mixed languages
- User ID of person who last changed the segment

Summary Data - Totals for the above figures

Figure 10a: Explanatory Notes for Figure 10

79/03/22 16.16.52 PAVE PAWS PSL VERSION 79/02/28. SUMMARY BY PROGRAMS CPCG= PSL. LEVEL= TST

UNIT NAME	SHRTNM	LANG	DATE/TIME CHANGED	NBR SEG	TOTL SIZE	NBR STUB	VN	EDN	INST	DATE/TIME COMPILED	OBJ SIZE *
PSL.ABORT	PSLABT	JOV	78/01/16 15.49.20	1	7	0	A0	3	19	78/12/19 13.49.15	16
PSL.ADD	PSLADD	JOV	78/12/19 16.34.18	9	254	0	A0	13	9	78/12/19 16.34.18	290
PSL.ALPHA	PSLALF	JOV	78/12/19 16.34.18	1	51	0	A0	2	9	78/12/19 16.34.18	90
PSL.AND	SSAND	COMP	78/12/12 17.27.14	1	11	0	A0	0	1	78/12/12 17.27.14	3
PSL.AUTHORIZATION.CHECKER	PSLAUT	JOV	78/11/01 22.12.07	17	521	0	A3	56	34	78/12/19 16.34.18	818
PSL.BINARY.TO.DECIMAL	BDEC	JOV	77/04/20 17.38.47	1	21	0	A0	2	10	78/12/19 13.49.15	26
PSL.CHECKPOINT	PSLCHK	JOV	78/08/09 08.28.17	12	295	0	B0	22	23	78/12/19 13.49.15	462
PSL.COMPILE	PSLCMP	JOV	78/12/11 19.39.00	8	333	0	B0	27	24	78/12/19 13.49.15	519
PSL.COMPOOL	PSLC	JOV	78/12/19 16.34.18	67	925	0	B0	70	29	78/12/19 16.34.18	4979
PSL.CONTROL	PSL1	JOV	79/01/15 13.48.07	19	470	0	B0	61	38	79/01/17 17.47.45	2485
PSL.COPY	PSLCPY	JOV	78/12/19 16.34.18	4	142	0	B0	10	16	78/12/19 16.34.18	174
PSL.DATA.STORAGE.AND.RETRIEVAL	SSDSAR	JOV	79/01/15 22.11.44	21	682	0	A0	82	13	79/01/15 22.11.44	1200
PSL.DCERROR.COUNTER	DCERRC	COMP	79/02/14 17.19.44	52	1275	0	A0	52	4	79/02/14 23.41.49	4562
PSL.DIAGNOSE	PSLDIA	JOV	78/12/20 13.45.32	8	221	0	A0	31	20	78/12/20 13.45.32	619
PSL.DIAGNOSTIC.STATISTICS.PRINTER	PSLSTA	JOV	77/05/26 12.43.15	11	174	0	A0	2	5	78/12/19 19.45.10	349
PSL.DIRECTIVE.CARD.PARSER	PARSER	JOV	79/01/15 13.48.07	18	497	0	B0	49	17	79/01/17 17.47.45	995
PSL.FIND.ASCII.KEYWORD	SSFIND	JOV	78/01/16 15.22.02	1	56	0	A0	4	10	78/12/19 19.45.10	70
PSL.INITIAL	PSLINI	JOV	78/12/20 13.45.32	4	133	0	B0	8	11	78/12/20 13.45.32	266
PSL.LOGEDIT	PSLLBE	JOV	78/11/02 18.42.48	12	262	0	A0	18	20	78/12/19 19.45.10	536
PSL.LIST	PSLIST	JOV	78/11/28 17.54.11	90	2168	0	B0	338	27	78/12/19 13.49.15	5627
PSL.MESSAGE	PSLERR	COMP	78/12/13 22.15.58	13	657	1	A0	40	53	78/12/13 22.15.58	1180
PSL.MODIFY	PSLMOD	JOV	79/01/17 17.47.45	35	931	0	B0	119	50	79/01/17 17.47.45	2482
PSL.NOS.CONTROL.CARDS	PSLJOV	JOV	78/12/20 13.45.32	13	319	0	A0	36	36	78/12/20 13.45.32	831
PSL.OBJECT.MANAGER	SSOMAN	JOV	77/09/15 20.59.12	3	60	1	A0	8	17	78/12/19 19.45.10	154
PSL.PUNCH	PSLPCH	JOV	79/01/15 13.48.07	8	177	0	A0	24	16	79/01/17 17.47.45	224
PSL.PURGE	PSLPUR	JOV	77/12/16 19.57.26	6	118	0	B0	28	17	78/12/19 19.45.10	175
PSL.READ.INPUT.CARD	PSLRDX	JOV	77/04/11 17.27.48	1	38	0	A0	0	8	78/12/19 19.45.10	42
PSL.READ.ONLY	PSL5	JOV	78/08/30 12.53.51	16	211	0	B0	35	33	78/12/19 19.45.10	3699
PSL.RESTORE	PSLRST	JOV	79/01/18 16.54.04	18	526	1	B0	44	24	79/01/18 16.54.04	822
PSL.RETID	PSL4	COMP	78/01/09 14.01.30	7	234	0	A0	29	24	78/01/10 01.38.34	330
PSL.SSID	SSID	COMP	78/01/18 14.49.23	12	291	0	A0	35	22	78/01/18 14.49.23	299
PSL.TWO	PSL2	JOV	78/09/26 09.38.08	38	741	0	B0	71	75	78/12/19 19.45.10	3743
PSL.XMIT	PSLXMT	JOV	77/12/12 11.59.25	2	76	0	A0	15	24	78/12/19 19.45.10	121

T O T A L S	TOTAL NUMBER PROGRAMS	TOTAL NUMBER SEGMENTS	TOTAL SIZE	TOTAL OBJECT SIZE	TOTAL NUMBER STUBS
	33	529	12877	38182	3

Figure 11. PROGRAM Summary

Top Line - Date and Time of computer run producing this listing
- Version ID (date) of the PSL
- Type of report requested
- CPCG for this page of the report
- Library Level for this page of the report

Tabular Data - Program longname
- Program shortname
- Language - JOV = JOVIAL
  - PDL = PDL
  - COMP = COMPASS
  - IFTR = IFTRAN
  - LEL = LEL (loader statements)
- Date and Time of most recent segment change
- Total number of segments, lines, and stubs
- Program Version (max of all segment versions)
- Program Edition (sum of all segment editions)
- Program Instance (incremented for each compile)
- Date and Time Compiled
- Object module size (decimal words)

Summary Data - Totals for the above figures

Figure 11a: Explanatory Notes for Figure 11

79/03/02 16.18.52 PAVE PAWS PSL VERSION 79/02/28. SUMMARY BY LIBRARY

LIBRARY LEVEL = PPS

--LANGUAGE--	--SEGMENTS--	--STUBS--	--PROGRAMS--	--LINES--	--CHANGES--
JOV	5	4	0	92	6
COMP	5	0	2	154	22
PDL	1	0	0	1	0
LEL	5	0	5	102	27

LIBRARY LEVEL = INT

--LANGUAGE--	--SEGMENTS--	--STUBS--	--PROGRAMS--	--LINES--	--CHANGES--
JOV	154	3	16	3898	779
COMP	35	8	8	1213	140
LEL	8	1	8	119	19

LIBRARY LEVEL = FIX

--LANGUAGE--	--SEGMENTS--	--STUBS--	--PROGRAMS--	--LINES--	--CHANGES--
JOV	5	0	1	158	9
COMP	1	0	0	30	8

LIBRARY LEVEL = TST

--LANGUAGE--	--SEGMENTS--	--STUBS--	--PROGRAMS--	--LINES--	--CHANGES--
JOV	128	0	30	4500	572
COMP	63	0	5	1790	114
LEL	13	0	13	245	79

LIBRARY LEVEL = FRZ

--LANGUAGE--	--SEGMENTS--	--STUBS--	--PROGRAMS--	--LINES--	--CHANGES--
JOV	459	4	33	11907	1099
COMP	69	2	9	2781	205
LEL	4	0	2	58	8

Figure 12. LIBRARY Summary

79/03/02 16.14.52 PAVE PAWS PSL VERSION 79/02/28. SUMMARY BY LIBRARY

	*** CODE PROGRESSION ***							*** CODE DURABILITY ***						
	--PRG--	--CPT--	--INT--	--FIX--	--TST--	--FRZ--	--DEL--	--PRG--	--CPT--	--INT--	--FIX--	--TST--	--FRZ--	--DEL--
ADTH	158	158	158	158	0	0	0	0	0	0	158	0	0	0
BLD.	5554	5475	5475	245	245	0	0	172	0	5217	0	169	0	0
DMV.	15	0	0	0	0	0	0	15	0	0	0	0	0	0
LPC.	1710	1710	1710	1710	1710	1695	0	0	0	0	0	128	1582	0
MMEP	724	724	724	724	724	724	0	0	0	0	0	34	690	0
PSL.	14210	14196	14196	14196	14196	12327	0	162	0	0	30	6028	7990	0

Figure 13. Progression/Durability Report

The Code Durability report acknowledges the fact that segments which have already been changed at lower library levels represent a discount to the figures of the Progression report. The accounting mechanism employed in the Durability report ignores segments which have already undergone further change at a lower level, i.e., the Durability report shows management that it is dangerous to consider a segment as having been successfully integrated when it has passed the INT level of the library if it is simultaneously undergoing change at the PRG level. The value of this report lies in complementing the Progression report in allowing management to answer questions such as "How good is the code that has been developed?" and "How much effort remains to be done?". To consider an extreme example, if the library only contains ten unique segments and they have all progressed to the TST level but nine of them have new changes introduced at PRG, the code is clearly not very "durable" and the progression numbers are apparently (but not necessarily) misleading. These discrepancies can only be resolved by management understanding of the technical status of the software at the higher level and the reasons behind the changes at the lower level. To calculate "durable" lines of code, the PSL counts each unique segment only once, and that at the lowest level of the library at which it appears.

4.0 PAVE PAWS DATA COLLECTION ENVIRONMENT

The controls inherent in the Program Support Library (PSL), and in the automated Trouble Reporting (TR) System provided for ease of automatic data collection, with a minimal amount of manual effort. Program modifications were made to the Program Support Library and Trouble Reporting System to provide for data collection reports. These were provided to RADC on a periodic (monthly) basis.

4.1 PSL Changes in Support of Data Collection. The Program Support Library programs were modified to read the compiler list output and determine compiler detected errors. A special data file was added to the PSL for the purpose of saving compiler detected errors. The contents of this data file were used as inputs to a report program on a weekly basis to produce the PSL Error Reports which were provided to RADC as part of the Data Collection Effort. Impact on the PSL users was minimal, with one additional field required for compilation (compile reason code). The compile reason codes are described in Figure 14. A list of the PSL Report Data is shown in Figure 15.

4.2 TR Data Base Reports. Using the TR Data Base maintained for PAVE PAWS, special TR reports were written for the purpose of data collection. The modified TR form (described in section 4.4) was used to provide input data for these reports, which were produced on a weekly basis. There were three reports used for TR Data Collection: CPCI, CPCG, and originating organization. The number of errors by error category was provide in the TR reports.

4.3 Data Collection CPCIs. A subset of the PAVE PAWS CPCIs was used for Data Collection (CPCIs 2, 3, 4, 5). Specific CPCGs are listed in Figure 16.

4.4 Manual Data Collection Form. The Trouble Report/Change Request form was modified to support Data Collection. This was accomplished by adding the Error Category field to the form. Figure 17a shows the sample TR form, and Figure 17b the Error Categories.

COMPILE REASON CODES

1.1 INITIAL PROGRAM COMPILE — INITIAL

This code should be used until the program compiles without compiler detected error.

1.2 KEYPUNCH ERROR — KEY

This code should be used when keypunching errors are being corrected.

1.3 DECK SETUP ERROR — SETUP

This code should be used when the compile is to correct a deck setup error such as using the wrong COMPOOL.

2.1 COMPUTATIONAL ERROR — COMP

This code should be used when correcting computational errors such as the wrong sign or wrong trigonometric function.

2.2 LOGIC ERROR — LOGIC

This code should be used when correcting logic errors such as NQ instead of EQ.

2.3 DATA BASE ERROR — DATA

This code should be used when correcting data base errors such as tables not correctly initialized.

2.4 I/O ERROR — IO

This code should be used to correct errors in using the IO facilities such as changing reads to puts or adding necessary WAIT statements.

3.1 SPECIFIED FUNCTION NOT IMPLEMENTED — SFNI

This code should be used to insert functions whose implementation has been deliberately delayed.

3.2 SPECIFIED INTERFACE NOT IMPLEMENTED — SINI

This code should be used to insert interface code which has been deliberately deferred.

4.1 UNSPECIFIED FUNCTION — FUNCHG

This code should be used to implement new or changed functions.

4.2 UNSPECIFIED INTERFACE — INTCHG

This code should be used to implement new or changed interfaces.

Figure 14. COMPILE REASON CODES

5.1 MEMORY OPTIMIZATION — MEMOPT

This code should be used to compile changes made to improve core memory utilization.

5.2 CPU TIME OPTIMIZATION — CPUOPT

This code should be used to compile changes made to improve CPU utilization.

5.3 LOGIC SIMPLIFICATION — LOGOPT

This code should be used to compile changes made to the program to make the logic easier to understand.

6.1 COMMENT — COMMENT

This code should be used when the compile is to verify the legality of comments.

6.2 EXTRA LISTING REQUIRED — LIST

This code should be used when the compile is to obtain an extra listing or an additional listing feature e.g., generated code.

6.3 OBJECT MODULE VERIFICATION — VERIFY

This code should be used when the purpose of the compile is to guarantee that the object and source code match. This code should also be used when a common include has been changed in another program.

7.1 COMPILER ERROR — COMPILER

This code should be used when investigating or correcting internal computer errors.

7.2 OPERATING SYSTEM ERROR — PPOS

This code should be used when correcting operating system errors.

7.3 PSL INTERNAL ERRORS — PSL

This code should be used when correcting PSL internal errors.

Figure 14. COMPILE REASON CODES (Continued)

DATA ON PSL DATA COLLECTION STATISTICS FILE

LONGNAME OF PROGRAM
FIRST TWO COMPILER ERRORS
SHORTNAME OF PROGRAM
COMPILER CPU TIME
PRECOMPILER CPU TIME
PROGRAM SIZE IN LINES
PROGRAM OBJECT MODULE SIZE
PROGRAM EDITION
COMPILE REQUESTOR
JULIAN DATE AND TIME
COMPILE TIME ERROR COUNT
PROGRAM (TOP SEGMENT) OWNER
PROGRAM LANGUAGE
USER PROVIDED COMPILE REASON

Figure 15. Data on PSL Data Collection Statistics File

PSL DATA COLLECTION CPCGs

CPCI 4
- PSL - Program Support Library
- LPC - PreCompiler
- MREP - PSL Management Reports

CPCIs 2 and 3
- COMM - Communications
- DISP - Displays
- DPCS - Data Processing Data Base
- MCTL - Mission Control
- RAM - Radar Manager
- RTM - Real Time Monitor
- RTSM - Real Time Simulation
- SGDB - SIMEX Global Data Base (CPCI 3)
- TGDB - TIMEX Global Data Base (CPCI 2)
- TRCK - Track
- TSG - Target Scenario Generation

CPCI 5
- DTRD - Data Reduction
- PRNT - Print
- STRP - Strip
- SORT - Sort

Figure 16. PSL Data Collection CPCGs

PAVE PAWS PROGRAM TROUBLE REPORT/CHANGE REQUEST

ORIGINATOR

TR ☐	ORIGINATOR	DATE	CPCI	FUNCTION/CPCG	PRIORITY ☐ EMERG ☐ URGENT ☐ ROUTINE	TR/CR NO.
CR ☐	SYSTEM BUILD ID	LEVEL	PROGRAM/DOC'T MOST AFFECTED	REF CHANGE NO(S)		

PROBLEM/CHANGE DESCRIPTION:

TEST IMPACTED: _____

ATTACHMENTS: ☐ON-LINE ☐DUMP ☐LISTING ☐OTHER _____ MGR APPROVAL DATE

BRIEF DESCRIPTION:

CCG

ACTION ASSIGNEE	DEPT	APP'L LEVEL ☐LCB ☐PRB ☐CCB ☐ECP	CCG PROCESSED BY: DATE:	FIX ELEMENTS

ACTION ASSIGNEE

CORRECTIVE ACTION DESCRIPTION: ✓ IF IMPACTED: ☐DOC'T ☐PDL ☐CODE

SEQ NUMBER	FUNCTION OR CPCG	DOC'T, PDL OR CODE
-01		
-02		
-03		
-04		
-05		
-06		
-07		
-08		
-09		
-10		

ERROR CATEGORY ☐ (See Reverse Side)

REJECT REASON (✓): ☐NON-PROBLEM ☐INSUFFICIENT DATA ☐DUPLICATE (REF_____) ☐OTHER

APPS

☐APPROVE ☐DISAPPROVE		☐APPROVE ☐DISAPPROVE		☐APPROVE ☐DISAPPROVE		☐APPROVE ☐DISAPPROVE	
CHIEF PRGMR	DATE	LCB	DATE	PRB	DATE	CCB	DATE

Figure 17a - Sample TR Form

ERROR CATEGORIES

1. Computational Error - Error in implementation of equations
2. Logic Error - Error in decision logic
3. Data Base Error - Error in data base definition
4. Input/Output Processing Error - Error in processing data items
5. Specified function not implemented - Missing code
6. Specified interface not implemented correctly - This could apply to hardware, operating system, other programs, common data areas, etc.
7. Unspecified function required - Additional problem definition needed
8. Unspecified interface not satisfied - This could apply to hardware, operating system, other programs, common data areas, etc.
9. Memory/throughput optimization
10. Design modification/enhancement
11. Documentation change only - type C spec change/user manual/PDL
12. Keypunch error
13. Deck setup - JCL/Procedure error
14. Configuration Error - i.e. Build uses mismatched code, wrong IGS package in Build, etc.

Figure 17b. Error Categories

4.5 Products. Samples of the TR reports and PSL Reports are shown in Figure 18 and 19 respectively. The compiler summary report presents tabular information for each compilation, including the CPU time of the pre-compiler and the compiler, the number of compiler errors, etc. The TR report shows the number of TR's of each error category broken down by originating organization (development, RAYTHEON, etc.) or TR series (JOVIAL, data dictionary, etc.).

PGM NAME	LEV	LANG	DATE AND TIME OF COMPILE	PGM EDTION.	LINES	OBJECT SIZE	COMP ERRS	COMPILE REASON	ERROR ID	OWNER	COMPILER	CPU TIME COMPILE	1 LPC
PSLAUT	FIX	JOV	22SEP79 8:41:27	54	822	001452	0	LOGIC		PH8VOG	IBMFIX	10	5.126
SSDSAR	FIX	JOV	22SEP79 8:41:27	77	1257	002232	0	FUNCHG		PH8DAD	IBMFIX	17	9.870
PSLPST	FIX	JOV	22SEP79 8:41:27	32	837	001405	0	FUNCHG		PH8JRL	IBMFIX	11	5.635
SSDSAR	INT	JOV	14NOV78 17:51: 7	80	1261	002260	0	LOGIC		PH8DAD	IBMWBV	17	9.876
PSLPST	INT	JOV	10NOV78 15:36:19	40	881	001443	0	FUNCHG		PH8JRL	IBMWBV	11	5.927
PSLPST	INT	JOV	10NOV78 17:13:47	38	881	001446	2	FUNCHG	JV177	PH8JRL	IBMWBV	11	5.962
PARSER	PRG	JOV	4NOV78 14: 9:52	46	773	001746	0	LISTING		PH8VOG	IBMWBV	11	5.669
PSLJOV	INT	JOV	3NOV78 16:35:27	35	517	001477	1	LOGIC	JV007	PH8JKL	IBMWBV	8	3.527
PSLC	PRG	JOV	2NOV78 20:18:40	66	1062	012430	0	COMPILE		PH8JLS	IBMWBV	0	9.462
PSLLBE	PRG	JOV	2NOV78 20:18:40	18	368	001030	0	LOGIC		PH8JRL	IBMWBV	6	2.978
PSLAUT	INT	JOV	1NOV78 22:12: 7	56	822	001452	0	SETUP		PH8VOG	IBMWBV	10	5.151
SSDSAR	INT	JOV	1NOV78 22:12: 7	79	1261	002260	0	SETUP		PH8DAD	IBMWBV	17	10.033
PSLPST	INT	JOV	1NOV78 22:12: 7	33	837	001405	0	SETUP		PH8JRL	IBMWBV	11	5.862
PSLLPC	INT	JOV	27OCT78 21: 3:41	128	2755	011653	0	LOGIC		IBM999	IBMWBV	40	20.841
PSLLPC	FIX	JOV	25OCT78 19:31:27	124	2746	011616	0	LOGIC		IBM999	IBMFIX	40	21.086
PSLABT	PRG	JOV	20OCT78 17:29:13	3	26	000023	0	LOGIC		PH8JKL	IBMSPS	0	.108
PSLABT	PRG	JOV	20OCT78 17: 6:39	3	26	000023	0	LOGIC		PH8JRL	IBMSPS	0	.104
PSLABT	PRG	JOV	20OCT78 16:37:36	3	26	000023	0	LOGIC		PH8JRL	IBMSPS	0	.111
PSLALF	PRG	JOV	20OCT78 16:37:36	1	84	000106	0	LOGIC		PH8JRL	IBMSPS	0	.359
PSLALF	PRG	JOV	20OCT78 17:29:13	1	84	000106	0	LOGIC		PH8JRL	IBMSPS	0	.335
PSLALF	PRG	JOV	20OCT78 17: 6:39	1	84	000106	0	LOGIC		PH8JRL	IBMSPS	0	.377
PSLPCH	PRG	JOV	20OCT78 17:29:13	20	264	000354	0	LOGIC		PH8JRL	IBMSPS	0	2.101
PSLAUT	INT	JOV	29SEP78 21:35:49	54	822	001452	0	LISTING		PH8VOG	IBMWBV	10	5.078
PSL1	INT	JOV	29SEP78 21:35:49	54	716	004604	0	LISTING		PH8JRL	IBMWBV	9	6.897
SSDSAR	INT	JOV	29SEP78 21:35:49	78	1261	002260	0	LISTING		PH8DAD	IBMWBV	17	9.864
PSLPST	INT	JOV	29SEP78 21:35:49	32	837	001405	0	LISTING		PH8JRL	IBMWBV	11	5.593
SSDSAR	FIX	JOV	28SEP78 17:36:36	78	1261	002260	0	FUNCHG		PH8DAD	IBMFIX	17	10.069
PSLPST	FIX	JOV	21SEP78 14: 2:22	31	829	001357	0	FUNCHG		PH8JRL	IBMFIX	10	5.577
PSL1	FIX	JOV	20SEP78 12:13:26	52	714	004604	0	LOGIC		PH8JRL	IBMFIX	9	6.869
SSDSAR	FIX	JOV	20SEP78 12:13:26	75	1248	002232	0	FUNCHG		PH8DAD	IBMFIX	17	9.706
SSDSAR	FIX	JOV	20SEP78 8:41:27	74	1247	002232	0	FUNCHG		PH8DAD	IBMFIX	16	9.641
PSL1	FIX	JOV	11SEP78 16:46:22	51	714	004604	0	LOGIC		PH8JRL	IBMFIX	9	7.023
PSLPST	FIX	JOV	11SEP78 16:48:22	30	809	001323	0	LOGIC		PH8JRL	IBMFIX	10	5.563
PSLLPC	PRG	JOV	6SEP78 14:21:53	127	2745	011646	0	SETUP		IBM999	IBMJIP	40	20.777
PSLAUT	PRG	JOV	6SEP78 10: 8:18	52	823	001454	0	VERIFY		PH8VOG	PH8JRL	10	5.074
PSLAUT	FIX	JOV	6SEP78 10: 8:18	52	823	001454	0	LISTING		PH8VOG	PH8FIX	10	5.188
PSL1	PRG	JOV	6SEP78 14:21:53	52	715	004602	0	SETUP		PH8JRL	IBMJIP	9	6.814
SSDSAR	PRG	JOV	6SEP78 14:21:53	62	982	001662	0	SETUP		PH8DAD	IBMJIP	13	7.173
SSDSAR	FIX	JOV	31AUG78 14:26: 6	62	983	001662	0	LOGIC		PH8DAD	PH8FIX	0	6.573
PSLAUT	PRG	JOV	30AUG78 12:53:51	51	820	001445	0	SETUP		PH8VOG	PH8JRL	0	4.982
PSLAUT	PRG	JOV	30AUG78 9:55:38	48	792	001417	0	SETUP		PH8VOG	PH8JRL	11	4.864
PSLAUT	FIX	JOV	30AUG78 10:10:59	51	820	001445	0	FUNCHG		PH8VOG	IBMFIX	0	5.034
PSLCHK	PRG	JOV	30AUG78 9:55:38	22	418	000716	0	SETUP		PH8JRL	PH8JRL	8	3.025
PSLCHK	PRG	JOV	30AUG78 12:53:51	22	418	000713	0	SETUP		PH8JRL	PH8JRL	0	3.012
PSL1	PRG	JOV	30AUG78 15:38: 3	46	649	004524	0	SETUP		PH8JRL	PH8JRL	8	5.786
PSL1	PRG	JOV	30AUG78 16:22:16	52	715	004602	0	SETUP		PH8JRL	PH8JRL	9	6.454

Figure 18. Sample PSL Report - Compiler Summaries

	DATA DICT	DATA RED	DISPLAY	JOVIAL	PROG DEV	RAYTHEON	RCL	
00 UNKNOWN	2	13	1	36	240	14		9
01CMPUTATN	0	1	0	0	13	0		0
02 LOGIC	0	9	11	0	219	3		17
03 I/O	12	7	1	0	155	0		0
04 DATA	0	1	0	0	3	0		0
05 SFN1	4	5	2	0	67	0		6
06 SINI	0	1	2	0	57	0		4
07 NEWFUNC	0	0	0	0	13	1		0
08 NEW INT	0	0	0	0	9	0		3
09 OPTIMIZ	0	0	0	0	29	0		1
10 REDESIN	0	6	0	0	154	0		2
11 DOCUMNT	0	0	0	0	41	0		0
12 KEYPNCH	0	0	1	0	1	0		0
13 SETUP	0	0	0	0	7	0		0
14 CONFIG	1	0	0	0	20	0		0
15 OPEN	6	12	0	8	78	0		2
16 REJ D	0	1	5	2	66	0		5
17 REJ I	0	0	0	0	1	0		2
18 REJ N	0	9	0	6	65	0		12
19 REJ X	1	9	2	1	37	1		4
TOTAL	26	74	25	53	1275	19		67

Figure 19. Sample TR Report

5.0 TECHNOLOGY ASSESSMENT

This section discusses the utility and effectiveness of the development tools and techniques which were used on PAVE PAWS. For the most part, the assessment of these tools is subjective, for although PAVE PAWS has been a very successful project, the apportionment of that success to the programming team, the project management, and the technology is very imprecise. Each of the major software engineering tools which was employed is discussed separately and includes an assessment of the acceptance of that tool by the software development organization.

5.1 Top-Down Design and Development. The top-down discipline, which really becomes established during the project design stage, requires that all thought processes start by addressing system-wide issues first and then flow downward from that point. This in turn requires that system designers do their work and make their decisions before work proceeds at the subsystem level or lower. Consequently, the total system design gains visibility and credibility right from the start; all subsequent design work is viewed as refinement, clarification, or addition of detail to what has gone before. By adhering to this discipline throughout subsystem and program development, global questions are resolved first, structure and interfaces are established, and additional detail is added through a natural process of step-wise refinement. (In traditional, or bottom-up thought processes, global questions are addressed much later in time and tend to be resolved in keeping with the sum of all the micro-decisions which have already been made. Unfortunately this rarely turns out to be the best solution and some breakage of existing design or code is likely.)

Because top-down development uses a "macro" perspective and functions are initially identified by reference (an INCLUDE statement which names the desired function), a high degree of design and program code segmentation is required. In general, it is desirable to restrict each segment of code to a single page. In this way programs grow through the inclusion of new pages in an already established structure. Design updates may thus be more readily communicated and understood while program development proceeds in similar steps.

A major advantage of top-down program implementation is that the program can be compiled and executed on the day that the first segment is written! Although this segment by itself may not actually do much more than initialize program variables, name the functions which are to be performed in that program, and exit, the program can be debugged of errors in syntax and compiler control statements immediately. It can be integrated with other programs in the system to test their interaction as well. Since the subsequent development of lower-level segments is only a refinement to an existing structure program testing can be accomplished continually, providing a regression test of existing code and incremental testing of new segments. Additionally, since control sections and data paths will be established early in the top-down approach, much less emphasis is placed on test driver programs.

The system perspective afforded by top-down techniques was very advantageous throughout the design phase of PAVE PAWS. Not only is this the proper perspective for software designers, but it is probably the single most effective perspective from which to present design to systems engineers, management, and the customer. Furthermore, since successive levels of design represent greater and greater degrees of detail, design reviews or presentations may be quite readily tailored to suit the needs of the audience by eliminating those levels which are too detailed.

During code development on PAVE PAWS most programmers began a series of compilations as soon as the first two or three segments were coded. In addition to providing early identification of syntax and data usage errors, this provided a welcome diversion from endless hours of coding. The compiler cross-reference listings also provide a very convenient point of reference for data item utilization when coding additional segments. Unit testing was begun as soon as a complete function was coded and testing results thus began to accrue much earlier than in traditional projects.

One last and very significant advantage accruing from top-down development is the easing of software development schedule interdependencies. Since the top level of each program is written very early in the game, interface testing is begun immediately and individual programs may be fully developed and tested while using only rudimentary versions of related programs.

5.2 Structured Coding. Although structured coding has been a controversial subject in the past, it is currently well accepted by the programming community. The requirement to restrict program logic statements to a standardized set of control forms and the prohibition against programmer generated branch instructions is one of the most significant advances in recent years. Suddenly programs can be read, understood, and debugged by someone other than the author! Additionally, because the code must be straight-forward in its logic flow, there are not as many hiding places for program bugs as there once were! Both of these are very important advantages of structured coding although it is again very difficult to quantify their effect. The benefits of standardization are felt very strongly during the project design phase when non-programmers form a significant part of the audience, and again in the maintenance period of the project, when a small number of people are assigned to maintain a large amount of code. The improved software quality assurance which derives from a lower incidence or program bugs due to the use of structured coding is a phenomenon which begins with the software design and stays with the software throughout its lifetime. It should also be pointed out here that part of the value attributed to structured coding comes about from program segmentation and the use of indented segment listings, which together serve to make program logic very apparent to the reader.

As one last rejoinder to the standard argument against structured coding, it must be noted that PAVE PAWS successfully met stringent real-time memory and throughput criteria. Although this did require the use of assembly language coding for a few very highly used subroutines, in no case was an argument put forth to violate structured coding techniques in order to achieve better performance. It is suspected that unstructured programs which are

tricky in an attempt to improve performance are likely to incur a performance reduction because of the overhead involved in making the tricks work. It is widely acknowledged that such programs will be extremely difficult to debug and maintain by other than the original program author.

5.3 Indented Segment and Program Listings. Given a highly segmented program and the use of structured programming, indented listings which graphically show the logic of a program are a valuable addition. (Refer to Figure 8 in Section 3 for an example.) The primary virtue of these listings is the almost instant comprehension of program logic structure, particularly in "either - or" cases. Note that by limiting segment sizes to 56 lines (one page), the likelihood of nested indentation pushing a card image too far to the right to be printed is almost neglibible (in fact, this has never occurred on PAVE PAWS).

Indented program listings are constructed by the PAVE PAWS PSL as an ordered collection of indented segment listings. Figure 20 represents a typical segment structure of a program where each block represents a segment and the order of printed segment listings is indicated. As an additional convenience, an indented "hierarchy" listing is printed in the front of each indented program listing. The hierarchy simply shows the relationship between the segments of the program and any subroutines which are called.

The physical structure of an indented program listing makes it an effective medium for design and code reviews. The limitation of segment size to a single page allows complete review of a single segment before selecting the path to be followed and essentially increasing the "magnification" being used. Surprisingly enough, these same features make indented program listings equally effective for debugging. Referring back to Figure 20, it can be seen that a bug in the lowest level segment in this structure can be reached from the top segment by going through no more than four segments. Assuming that the program is structured along functional lines, isolating a program logic bug to a single segment of code is usually a very straight forward procedure.

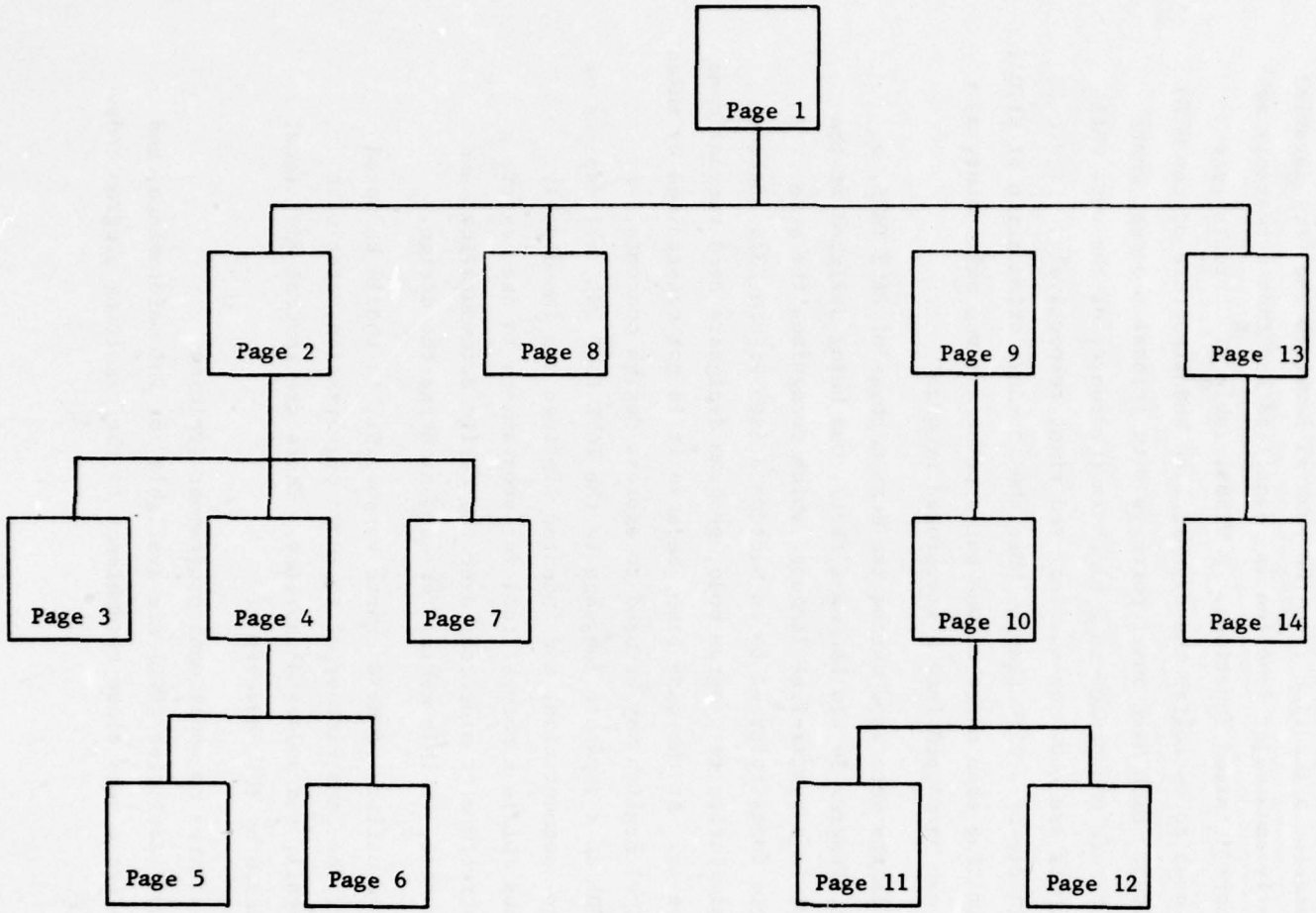


Figure 20. Program Segment Structure

5.4 Program Design: HIPO and PDL. Hierarchy plus Input-Process-Output (HIPO) is a documentation technique consisting of a set of diagrams which graphically describe a function from the general level to the very detailed level. Initially each major function is identified and then repeatedly subdivided into more detailed functions. A Visual Table of Contents (see Figure 21) is used to establish the organization and structure of the HIPO charts themselves. Each HIPO chart portrays a functional process, where processing steps are enumerated in a block in the center of the page while inputs and outputs are shown on the left and right respectively. Figure 22 provides an example of a HIPO chart. Note the top-down orientation of HIPO's and that by limiting each chart to one entry point and one exit point, a HIPO function can be mapped into a structured program!

Although HIPO charts were used during the design phase of PAVE PAWS, a companion tool, Program Design Language (PDL), was being utilized at the same time. PDL is a syntax-free language which recognizes the same structured logic forms referred to in Section 3 (see Figure 23). Because of its great similarity to program code, program designers need virtually no training to use it. At the same time, because it is not constrained by rules of syntax, normal English may be used to express design concepts. By implementing PDL as a separate language in the PAVE PAWS PSL, all aspects of top-down design, segmentation, and indented listings are immediately available. Thus PDL is a natural tool for programmers to use, exerts a well defined structure or hierarchy over the design documentation, and provides a readable, visible medium for communicating the design.

In comparing the utility of HIPO charts versus PDL, it should be noted that they share the same virtues of top-down organization, step-wise addition of detail, and understandability. There are several additional advantages offered by PDL, however -

a. PDL requires no additional programmer training,
b. Support facilities (PSL) are available for PDL maintenance, and
c. PDL bears a very close resemblance to the resulting program code.

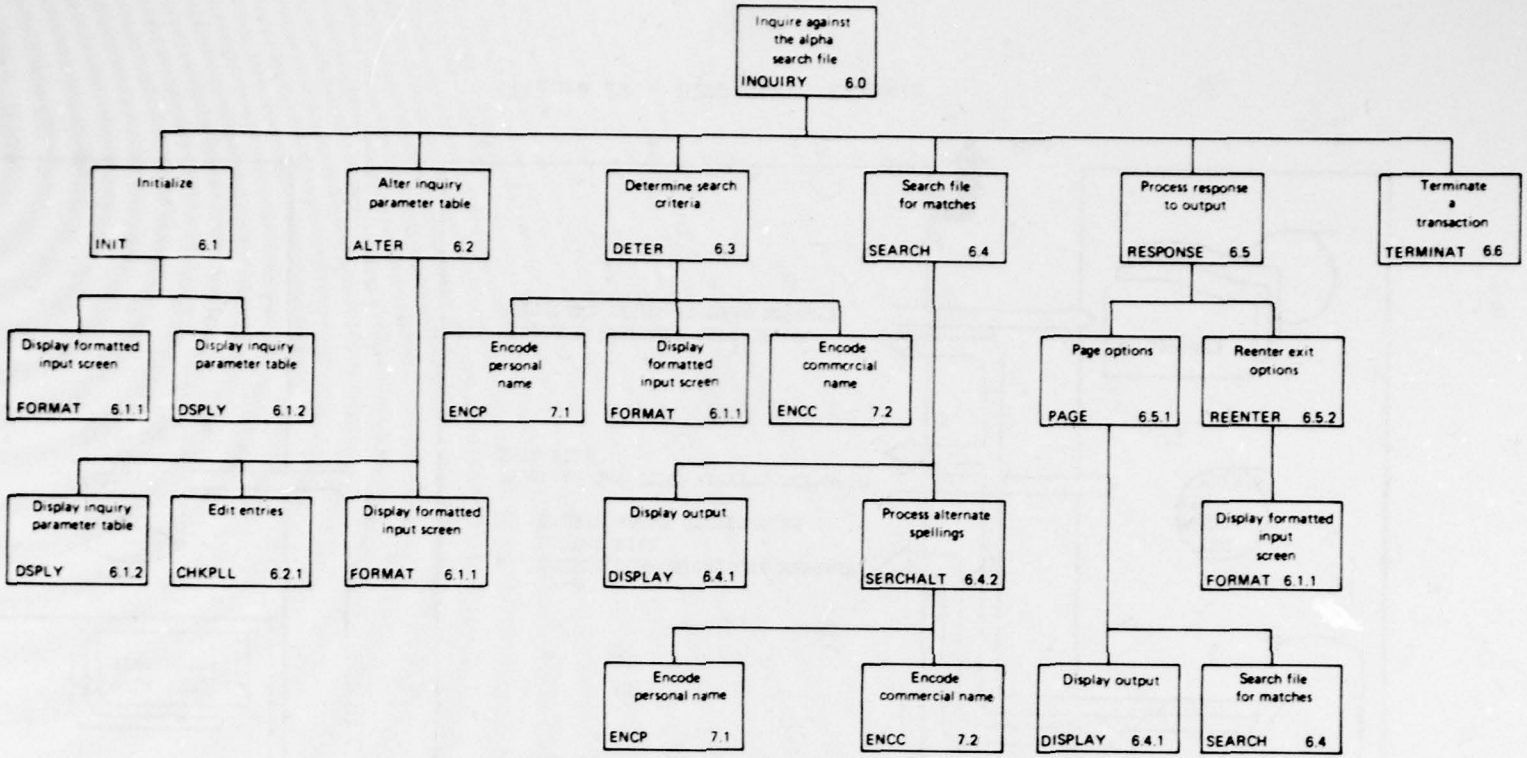


Figure 21. Visual Table of Contents - Example

Diagram ID: 3.4.2 Name: TARGET SCENARIO GENERATOR CPCG Version: Page 1 of 1

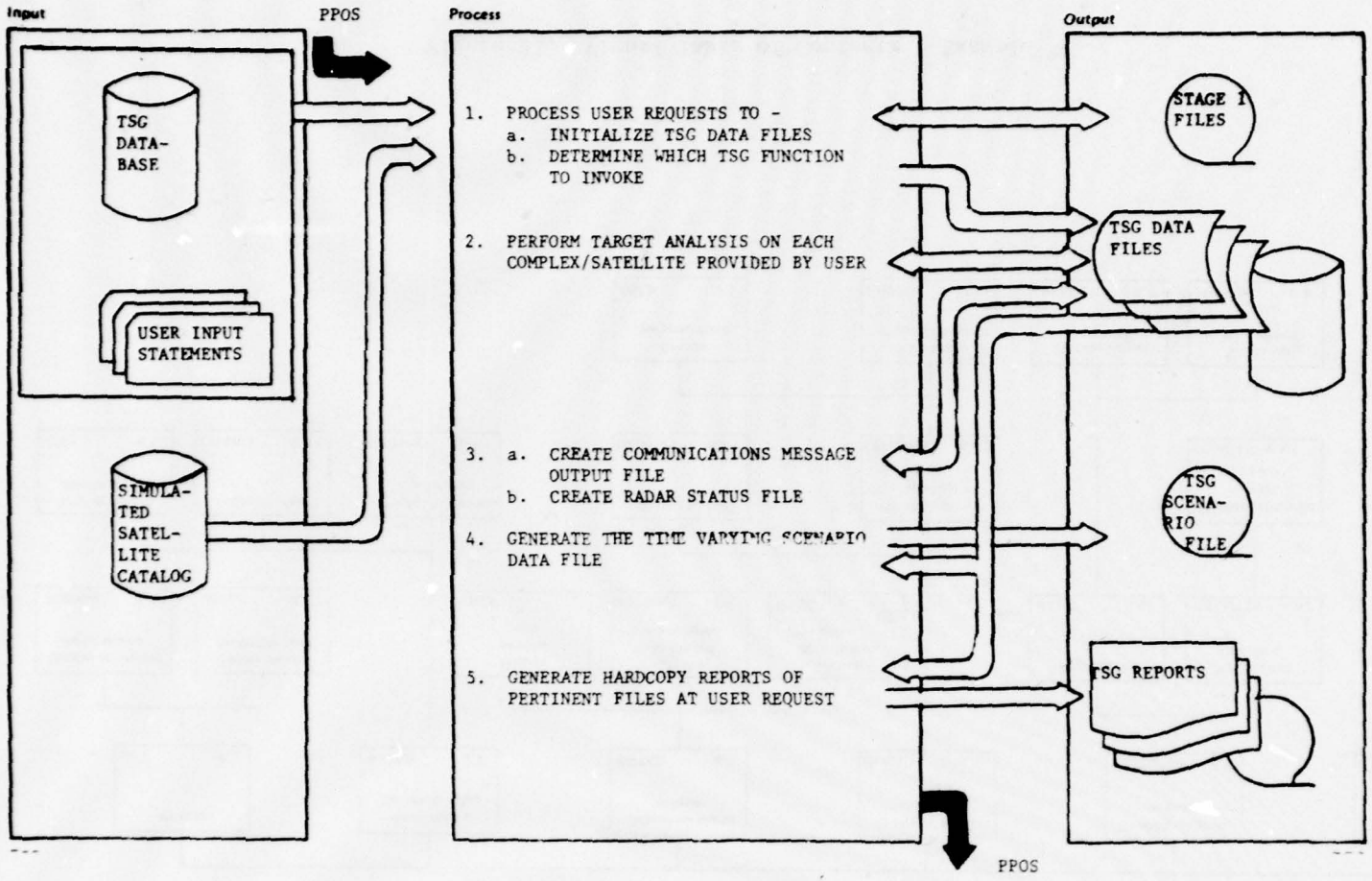


Figure 22. HIPO Chart Example

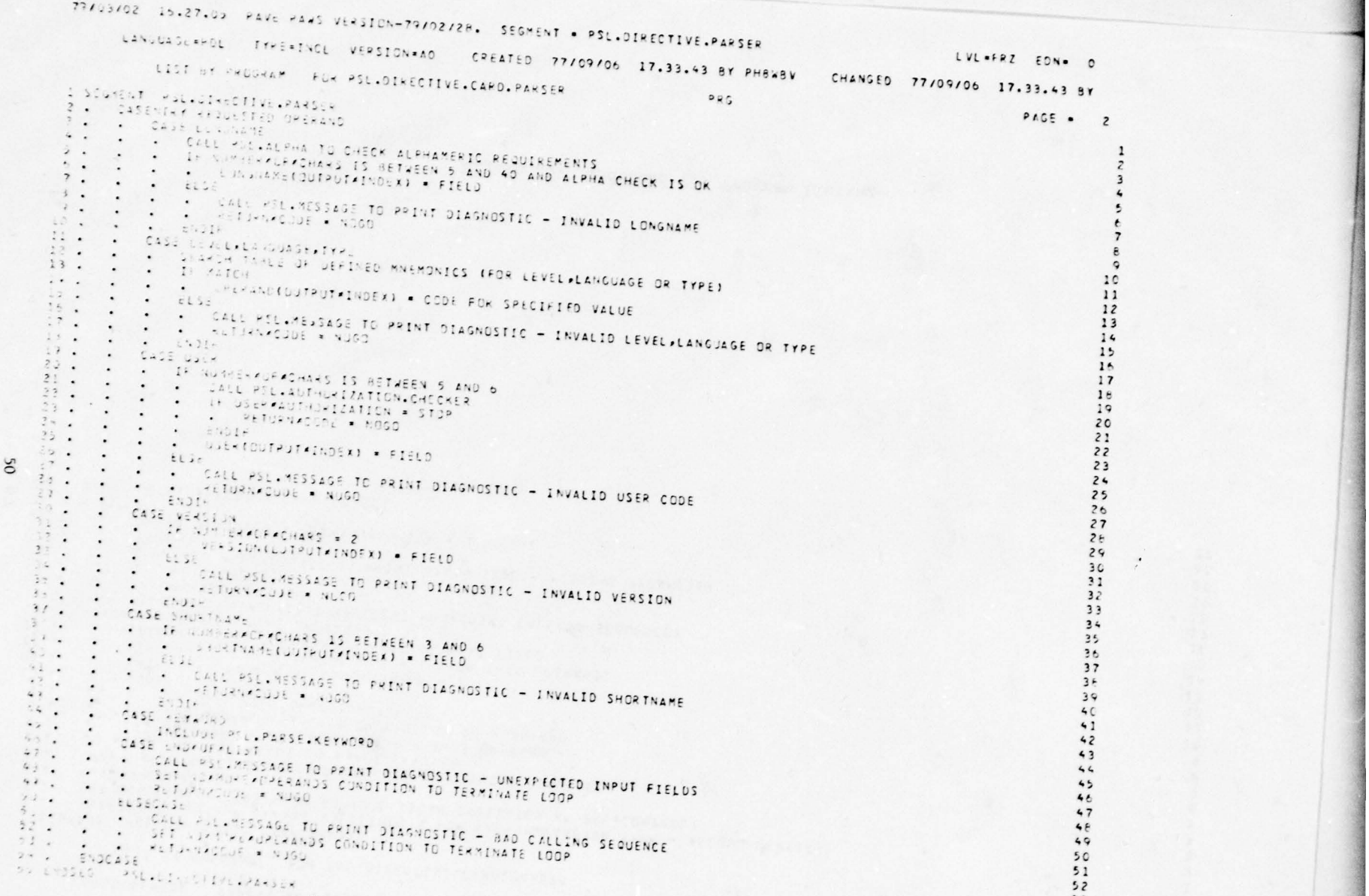
```
79/03/02  16.27.09  PAVE PAWS VERSION-79/02/28.  SEGMENT = PSL.DIRECTIVE.CARD.PARSER                    LVL=FRZ  EDN=  0   PARSER

      LANGUAGE=PDL    TYPE=SUBR  VERSION=A0    CREATED  77/09/06  17.33.43 BY PH8WBV    CHANGED  77/09/06  17.33.43 BY

          LIST BY PROGRAM   FOR PSL.DIRECTIVE.CARD.PARSER                PRG                                  PAGE =   1

 1 SEGMENT  PSL.DIRECTIVE.CARD.PARSER                                                                                  1
 2 .    INITIALIZE OUTPUT ARRAYS (5 ELEMENTS FOR EACH PARAMETER TYPE - ALLOWS REPEATS)                                 2
 3 .    GET SCAN PARAMETERS FROM COMPOOL (SCAN INITIATED BY PSL.CONTROL)                                               3
 4 .    RETURN#CODE = GO                                                                                               4
 5 .    START WITH FIRST REQUESTED OPERAND IN CALLING SEQUENCE                                                         5
 6 .    DO WHILE MORE OPERANDS ON INPUT CARD(S)                                                                        6
 7 .    .   OUTPUT#INDEX = REPEAT#COUNT FOR THIS OPERAND                                                              7
 8 .    .   IF NUMBER#OF#CHARS OR 0 OF OPERAND IS REQUIRED                                                            8
 9 .    .   .   INCLUDE PSL.DIRECTIVE.PARSER                                                                         9
10 .    .   ENDIF                                                                                                    10
11 .    .   OPERAND#NUMBER = OPERAND#NUMBER + 1                                                                      11
12 .    .   REPEAT#COUNT = REPEAT#COUNT + 1 (FOR THIS OPERAND)                                                       12
13 .    .   CALL     PSL.CARD.SCAN TO EXTRACT NEXT FIELD                                                            13
14 .    ENDDO - WHEN NO MORE OPERANDS                                                                              14
15 .    DO WHILE NOT END#OF#LIST (PROCESS REMAINING CALLING SEQUENCE)                                              15
16 .    .   IF OPERAND IS REQUIRED                                                                                 16
17 .    .   .   RETURN#CODE = NOGO                                                                                 17
18 .    .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - MISSING PARAMETER                                           18
19 .    .   ENDIF                                                                                                  19
20 .    .   OPERAND#NUMBER = OPERAND#NUMBER + 1                                                                    20
21 .    ENDDO                                                                                                      21
22 ENDSEG   PSL.DIRECTIVE.CARD.PARSER                                                                              22
```


Figure 23. Indented PDL Program Listing



```
77/09/02  15.27.03  PAVE PAWS VERSION=77/02/28.  SEGMENT = PSL.DIRECTIVE.PARSER

      LANGUAGE=PDL   TYPE=INCL  VERSION=A0    CREATED  77/09/06  17.33.43 BY PH8ABV     CHANGED  77/09/06  17.33.43 BY

                                                                                                          LVL=FRZ  EDN=  0

          LIST BY PROGRAM   FOR PSL.DIRECTIVE.CARD.PARSER                                  PRG

                                                                                                          PAGE =   2

1  SEGMENT  PSL.DIRECTIVE.PARSER                                                                                    1
2  .   CASE ENTRY REQUESTED OPERAND                                                                               2
3  .   .   CASE LONGNAME                                                                                          3
4  .   .   .   CALL PSL.ALPHA TO CHECK ALPHAMERIC REQUIREMENTS                                                    4
5  .   .   .   IF NUMBER.OF.CHARS IS BETWEEN 5 AND 40 AND ALPHA CHECK IS OK                                      5
6  .   .   .   .   LONGNAME(OUTPUT.INDEX) = FIELD                                                               6
7  .   .   .   ELSE                                                                                             7
8  .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID LONGNAME                                      8
9  .   .   .   .   RETURN.CODE = NOGO                                                                           9
10 .   .   .   ENDIF                                                                                           10
11 .   .   CASE LEVEL.LANGUAGE.TYPE                                                                           11
12 .   .   .   SEARCH TABLE OF DEFINED MNEMONICS (FOR LEVEL,LANGUAGE OR TYPE)                                   12
13 .   .   .   IF MATCH                                                                                        13
14 .   .   .   .   OPERAND(OUTPUT.INDEX) = CODE FOR SPECIFIED VALUE                                           14
15 .   .   .   ELSE                                                                                           15
16 .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID LEVEL,LANGUAGE OR TYPE                       16
17 .   .   .   .   RETURN.CODE = NOGO                                                                         17
18 .   .   .   ENDIF                                                                                         18
19 .   .   CASE USER                                                                                          19
20 .   .   .   IF NUMBER.OF.CHARS IS BETWEEN 5 AND 6                                                         20
21 .   .   .   .   CALL PSL.AUTHORIZATION.CHECKER                                                            21
22 .   .   .   .   IF USER.AUTHORIZATION = STOP                                                              22
23 .   .   .   .   .   RETURN.CODE = NOGO                                                                     23
24 .   .   .   .   ENDIF                                                                                      24
25 .   .   .   .   USER(OUTPUT.INDEX) = FIELD                                                               25
26 .   .   .   ELSE                                                                                           26
27 .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID USER CODE                                   27
28 .   .   .   .   RETURN.CODE = NOGO                                                                         28
29 .   .   .   ENDIF                                                                                         29
30 .   .   CASE VERSION                                                                                       30
31 .   .   .   IF NUMBER.OF.CHARS = 2                                                                        31
32 .   .   .   .   VERSION(OUTPUT.INDEX) = FIELD                                                             32
33 .   .   .   ELSE                                                                                           33
34 .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID VERSION                                     34
35 .   .   .   .   RETURN.CODE = NOGO                                                                         35
36 .   .   .   ENDIF                                                                                         36
37 .   .   CASE SHORTNAME                                                                                     37
38 .   .   .   IF NUMBER.OF.CHARS IS BETWEEN 3 AND 6                                                         38
39 .   .   .   .   SHORTNAME(OUTPUT.INDEX) = FIELD                                                           39
40 .   .   .   ELSE                                                                                           40
41 .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID SHORTNAME                                   41
42 .   .   .   .   RETURN.CODE = NOGO                                                                         42
43 .   .   .   ENDIF                                                                                         43
44 .   .   CASE KEYWORD                                                                                       44
45 .   .   .   INCLUDE PSL.PARSE.KEYWORD                                                                     45
46 .   .   CASE ENDOFLIST                                                                                     46
47 .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - UNEXPECTED INPUT FIELDS                                 47
48 .   .   .   SET NUMBER.OF.OPERANDS CONDITION TO TERMINATE LOOP                                            48
49 .   .   .   RETURN.CODE = NOGO                                                                            49
50 .   .   ELSECASE                                                                                          50
51 .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - BAD CALLING SEQUENCE                                   51
52 .   .   .   SET NUMBER.OF.OPERANDS CONDITION TO TERMINATE LOOP                                            52
53 .   .   .   RETURN.CODE = NOGO                                                                            53
54 .   ENDCASE                                                                                              54
55 ENDSEG   PSL.DIRECTIVE.PARSER                                                                            55
```

Figure 23. Indented PDL Program Listing (Cont'd)

```
79/03/02  15.27.05  PAVE PAWS VERSION-79/02/28.  SEGMENT = PSL.PARSE.KEYWORD                    LVL=FRZ  EDN=  0

      LANGUAGE=PDL    TYPE=INCL  VERSION=A0    CREATED  77/09/06  17.33.43 BY PH8WBV    CHANGED  77/09/06  17.33.43 BY

          LIST BY PROGRAM   FOR PSL.DIRECTIVE.CARD.PARSER                PRG                          PAGE =  10

 1 SEGMENT  PSL.PARSE.KEYWORD                                                                          1
 2 .   IF NUMBER OF CHARS IS BETWEEN 1 AND 10                                                         2
 3 .   .   KEYWORD(OUTPUT INDEX) = FIELD                                                            3
 4 .   .   IF LAST DELIMITER WAS EQUALS (=)                                                         4
 5 .   .   .   INCLUDE PSL.CARD.SCAN TO EXTRACT KEYWORD TEXT SEGMENT                               5
 6 .   .   .   DO UNTIL NO MORE DATA OR PARENTHESES BALANCE OR RETURN CODE = NOGO                   6
 7 .   .   .   .   SCAN CHARACTERS IN KEYWORD TEXT SEGMENT                                         7
 8 .   .   .   .   ADD ONE TO PAREN COUNT FOR LEFT PARENTHIS                                       8
 9 .   .   .   .   SUBTRACT ONE FROM PAREN COUNT FOR RIGHT PARENTHESIS                            9
10 .   .   .   .   IF NO MORE THAN 40 CHARACTERS IN KEYWORD TEXT TOTAL (ALL SEGMENTS)              10
11 .   .   .   .   .   MOVE THIS SEGMENT INTO KEYWORD TEXT                                       11
12 .   .   .   .   .   UPDATE TOTAL CHARACTER COUNT                                             12
13 .   .   .   .   ELSE                                                                           13
14 .   .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID KEYWORD TEXT STRING        14
15 .   .   .   .   .   RETURN CODE = NOGO                                                        15
16 .   .   .   .   ENDIF                                                                         16
17 .   .   .   .   CALL PSL.CARD.SCAN TO EXTRACT NEXT INPUT FIELD                               17
18 .   .   .   ENDDO                                                                            18
19 .   .   .   KEYWORD LENGTH(OUTPUT INDEX) = TOTAL CHARACTER COUNT                             19
20 .   .   .   IF PAREN COUNT IS NOT ZERO OR TOTAL CHARACTER COUNT IS ZERO                       20
21 .   .   .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - FIELD IMPROPERLY TERMINATED           21
22 .   .   .   .   RETURN CODE = NOGO                                                           22
23 .   .   .   ENDIF                                                                            23
24 .   .   ENDIF                                                                               24
25 .   ELSE                                                                                     25
26 .   .   CALL PSL.MESSAGE TO PRINT DIAGNOSTIC - INVALID KEYWORD                              26
27 .   .   RETURN CODE = NOGO                                                                   27
28 .   ENDIF                                                                                    28
29 ENDSEG   PSL.PARSE.KEYWORD                                                                   29
```


Figure 23. Indented PDL Program Listing (Cont'd)

```
77/03/02  15.27.09  PAVE PAWS VERSION-77/02/28.  SEGMENT = PSL.CARD.SCAN                    LVL=FRZ  EON=  0   PICKER

      LANGUAGE=PDL   TYPE=LOCL  VERSION=A0    CREATED  77/09/06  17.33.43 BY PH8WBV    CHANGED  77/09/06  17.33.43 BY

          LIST BY PROGRAM   FOR PSL.DIRECTIVE.CARD.PARSER                PRG                          PAGE =  11

 1 SEGMENT  PSL.CARD.SCAN                                                                                          1
 2 .   IF ANOTHER OPERAND IS INDICATED (LAST DELIMITER = COMMA)                                                    2
 3 .   .   IF NEXT CHARACTER IS BLANK OR END-OF-CARD                                                             3
 4 .   .   .   CALL PSL.READ.INPUT.CARD - DIRECTIVE IS CONTINUED ON NEXT CARD                                     4
 5 .   .   .   IF THE CARD CONTAINS $ IN COLUMN 1                                                               5
 6 .   .   .   .   CALL PSL.MESSAGE - INVALID CONTINUATION CARD                                                 6
 7 .   .   .   .   RETURN#CODE = NOGO                                                                           7
 8 .   .   .   ELSE                                                                                            8
 9 .   .   .   .   CALL PSL.MESSAGE TO PRINT CONTINUATION CARD                                                 9
10 .   .   .   .   CALL PSL.SCAN.ASCII.STRING TO LOCATE FIRST NON-BLANK CHARACTER                              10
11 .   .   .   .   SET SCAN PARAMETERS TO POINT TO FIRST NON-BLANK CHARACTER                                    11
12 .   .   .   ENDIF                                                                                           12
13 .   .   ENDIF                                                                                               13
14 .   .   CALL PSL.SCAN.ASCII.READ TO EXTRACT NEXT DATA FIELD (MAY BE NULL)                                    14
15 .   ELSE                                                                                                    15
16 .   .   SET NO#MORE#OPERANDS CONDITION TO TERMINATE PROCESSING                                              16
17 .   ENDIF                                                                                                   17
18 END.EG   PSL.CARD.SCAN                                                                                      18
```


Figure 23. Indented PDL Program Listing (Cont'd)

Although this suggests that PDL be used exclusively instead of HIPO, a more temperate conclusion is appropriate - don't use PDL and HIPO to meet the same objectives. Experience on PAVE PAWS indicates that HIPO charts can be used effectively at the system and subsystem level but become cumbersome and redundant with PDL when taken more than the first few levels deep.

It is also appropriate to comment on the maintenance of design documentation. Experience on PAVE PAWS indicates that HIPO's and PDL (or their equivalent) are not only useful but necessary for the software design, development, management, and procurement communities during the design phase of the project. It provides the technical foundation for the entire development period while simultaneously serving as the means by which technical direction and scope are communicated and understood throughout the project. As the implementation cycle begins, however, questions and changes arise which require deviation from the documented design. This is a natural phenomenon which should not cause undue concern as long as the basic design intent is still intact. Under these circumstances there is no immediate need to update the design documentation - the procuring agency and the project management understand the design on a conceptual level while the programmers reflect design variations directly in the code. When and why, then, is the software design documentation ever updated? The only apparent reason to update and reissue software design documentation are -

a. To correct the documents of record.

b. To establish an effective mechanism to communicate design to a project newcomer.

c. To provide a bridge between system concepts and implementation for a maintenance group.

Assuming that one or more of these conditions holds, it is the author's opinion that the cost of updating design documentation is minimized by performing that function as seldom as is necessary to satisfy the users. This includes a "hands-off" approach while the software is developed or changed, followed by a periodic review, update, and republication to bring the design and the product back together again.

5.5 Hierarchical Library. The hierarchical library implemented in the PAVE PAWS PSL (see Section 3.4) was extremely useful throughout the development and test phases of the project. The separation afforded by the various levels provided stability at the upper levels with complete freedom of change at lower levels. Figures 24 thru 28 give an example of the progress of a single program through the lowest three levels of the library. In Figure 24, the program top segment has been coded and entered into the library at the PRG level. In the example shown, this segment references (via INCLUDE) four other segments, for which stubs (placeholders) are created. Following successful compilation of this program it was XMIT'ed to the CPT level where it was to undergo group testing under the control of the Chief Programmer. This is reflected in Figure 25. Figure 26 portrays the ongoing code development being done by the programmer at the PRG level. Note that this in no way affects the group testing being done at a higher level. Figure 27 indicates that the Chief Programmer was able to perform satisfactory group testing despite the fact that the majority of the function of this program was not yet implemented. With the concurrence of the integration team the program has been moved from CPT to INT and subsequently the program at PRG was moved to CPT. Figure 28 now shows the entry of two new segments at the PRG level, but more ominously, also shows changes to existing segments. Happily enough, these changes are still segregated from users of higher levels - they retain full control over the program configuration for the library level at which they are working. At this point it is helpful to point out the effective configuration at each level of the library -

at INT - T_o/stub/stub/stub/stub

at CPT - $T_o/A_o/B_o$/stub/stub

at PRG - $T_1/A_1/B_o/C_o/D_o$

LEVEL	TOP SEGMENT	SEGMENT A	SEGMENT B	SEGMENT C	SEGMENT D
INT					
CPT					
PRG	T_o	STUB	STUB	STUB	STUB

Figure 24. Program Configuration After Entry of Initial Segment

LEVEL	TOP SEGMENT	SEGMENT A	SEGMENT B	SEGMENT C	SEGMENT D
INT					
CPT	T_o	STUB	STUB	STUB	STUB
PRG					

Figure 25. Program Configuration After XMIT to CPT Level

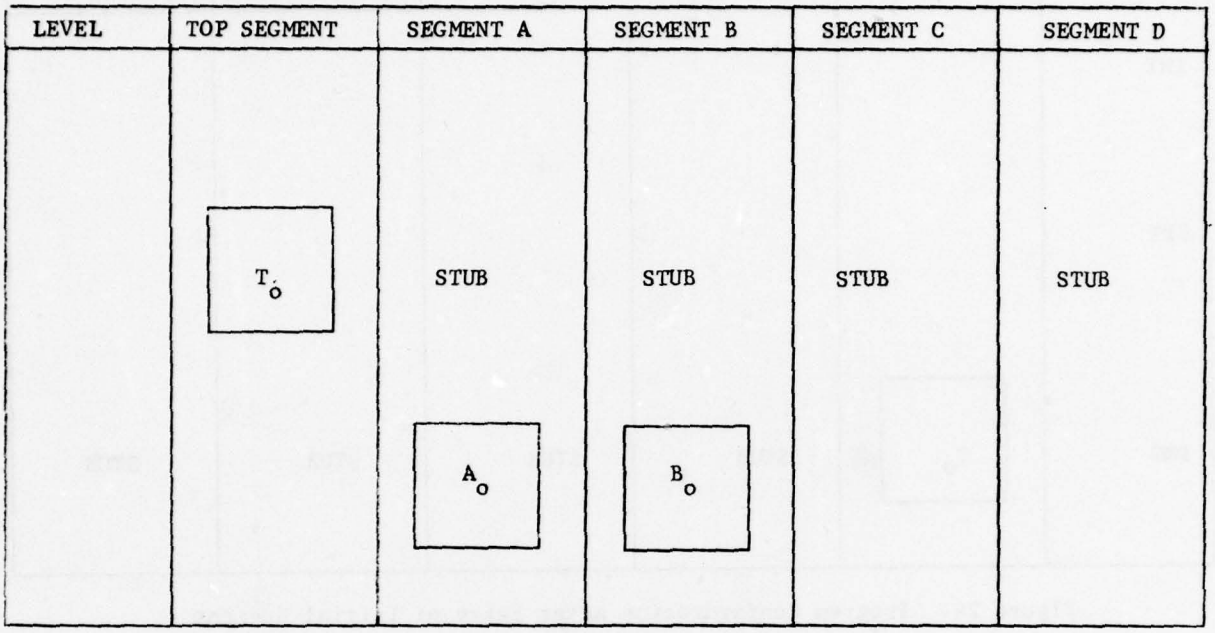


Figure 26. Program Configuration After Entry of Segments A and B

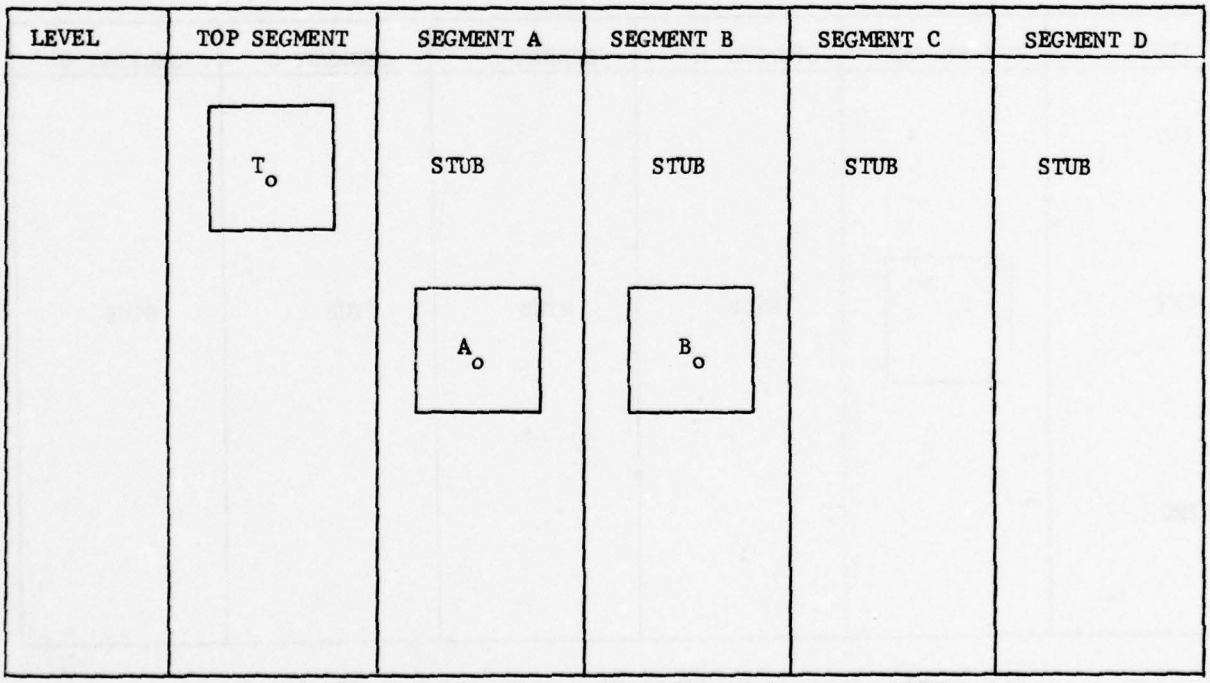


Figure 27. Program Configuration After Subsequent XMITs

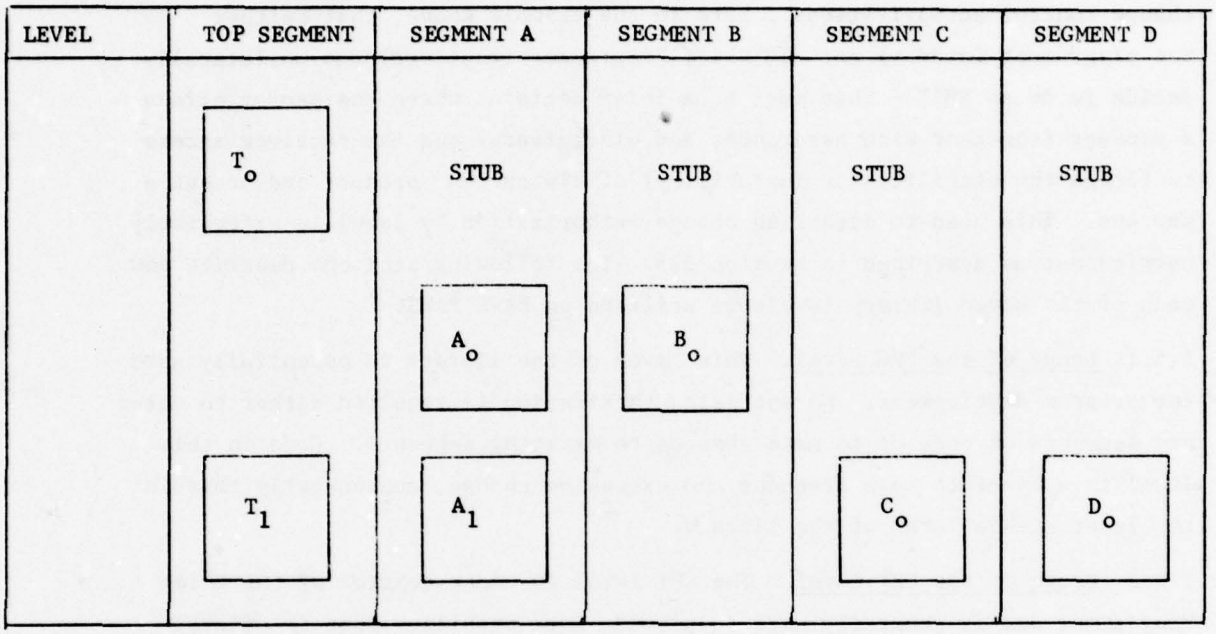


Figure 28. Program Configuration After Further Changes

The concept of library levels and their usage ties in very closely with change control authorizations. Note in the example above, that neither the programmer (sender) nor the Chief Programmer (receiver) can unilaterally decide to do an XMIT - this must be a joint decision where the sender offers a product (together with assurances and disclaimers) and the receiver agrees to forego the stability (or instability) of his current product and accept a new one. This need to establish change authorization by level is effectively carried out as described in Section 3.5. The following sections describe how each of the seven library levels is utilized on PAVE PAWS.

5.5.1 Usage of the PRG Level. This level of the library is essentially used for program development. No special authorization is required either to enter new segments of code or to make changes to existing segments. Code in this level is subject to both frequent and extensive change, consequently this is the least stable level of the library.

5.5.2 Usage of the CPT Level. The CPT level is under control of the Chief Programmer and is generally used to provide more stability than is offered at the PRG level. It may be used as the first point of program integration or it may be used to make high confidence or localized changes separately from the code at PRG. The authorization scheme in the PSL allows each Chief Programmer to perform XMIT's to the CPT level. No additional procedural constraints are placed upon this transaction due to the close working relationships within a Chief Programmer Team.

5.5.3 Usage of the INT Level. A separate integration team was utilized on PAVE PAWS to perform basic integration testing at the system level. Their responsibility was to establish stable and rational system operation in order to allow the functional test team to begin their testing. Although the integrators were authorized to XMIT code to the INT level, a formal procedure was followed to ensure documentation of software deliveries, including a list of all problems which had been corrected. This procedure required that the Chief Programmer list all the programs to be XMIT'ed together with a list of all problems corrected on a Software Change Release Notice (SCRN). The SCRN was then signed by the manager (leader) of the integration team before the delivery was performed.

5.5.4 Usage of the FIX Level. This level, which is controlled by the Functional Test Group, is a low-traffic level containing specific corrections for software at the next higher level (TST). Changes can be made directly at this level if necessary to fix specific urgent problems. XMIT's of individual programs may also be performed following the SCRN procedure with the concurrence of the Functional Test manager. This level is separate from the TST level to avoid those situations where "the cure is worse than the disease".

5.5.5 Usage of the TST Level. This is the primary level of interest for the Functional Test group. It is highly stable and is the level from which the Qualification Tests are normally run. The emphasis at this level is to push the entire system to its next functional performance benchmark.

5.5.6 Usage of the FRZ Level. The FRZ level, which on PAVE PAWS is under control of the prime contractor, is used for deliveries from TST following successful completion of Qualification Testing. Software at this level is under ECO/ECP control.

5.5.7 Usage of the DEL Level. This level contains the software configuration which is operational. It is controlled by the acquiring agency.

5.6 Chief Programmer Team/Librarian Operations. As implemented on PAVE PAWS, Chief Programmer Teams require a very heavy technical involvement on the part of the Chief Programmer in software design, implementation of key programs, and review of the design and code of other members of the team. In general this included one or two key Backup Programmers who developed their own areas of specialization. Although the management responsibilities of the Chief Programmers detracted somewhat from their technical efforts, it seems important that the person making schedule and resource decisions (the manager) be as technically involved as possible. This makeup of a Chief Programmer Team was successful on PAVE PAWS and would be recommended for use on other projects.

Although Programmer Librarians were used on PAVE PAWS, they were not used in the classical role. Current literature calls for the Librarian to perform all the keypunching, job submittal, and filing of listings for a single Chief Programmer Team. The Librarian's role is to act as the central clearing house for all these operations. On PAVE PAWS although

the Librarian performed all of these services they did not act as the single focal point. This came about in part because the number of librarians could not keep up with heavy keypunch demands and as second and third shift operations increased, programmers were left more and more to their own devices. Contrary to popular opinion, it is not a total waste for a programmer to perform his own keypunching (within reason). It gives him the chance to simultaneously review his coding and correct coding or logic errors on the spot.

5.7 Structured Design/Structured Code Walkthroughs. Structured Walkthroughs were used extensively on PAVE PAWS with great success. Segmented, structured code with indented listings are an excellent vehicle for communicating design or implementation. An important distinction should be made, however, between the purpose of a design review and the purpose of a code review. A design review should be oriented toward presenting program design to a team of people (including systems engineers, customer personnel, and testers) and soliciting their comments on its validity, completeness, etc. A code review on the other hand should involve at most two people other than the author and should be done with a great deal of attention to detail, even going so far as to detect snytax and data usage errors. Done in this fashion, code reviews are not only informative but highly productive. In both types of reviews, indented listings are provided for each member of the audience and the author acts as a moderator in explaining the design or code. The author should maintain a record of all unanswered questions and discrepancies which then becomes an action item list at the conclusion of the review.

5.8 Management Statistics Collection/Reporting. The reporting capabilities of the PAVE PAWS PSL as described in Section 3.7 were of limited use to the programmers and Chief Programmers. Reports were used as a confirmation following a major delivery but were only rarely referred to in other instances. Middle and upper management made religious use of the Progression and Durability reports however. This is a natural phenomenon

when you recognize that programmers view progress in terms of solving technical problems while management is less concerned with "the problem of the day" and is more interested in demonstrated rates of progress. Coding and testing rates can be realistically measured by plotting the outputs of these reports. Figure 29 shows prototype software development curves for the theoretical case and for phased deliveries. Figures 30 through 37 present actual data for CPCI 2 as experienced on PAVE PAWS. Figures 38 through 40 similarly provide data for CPCI-3. The major Qualification Test dates have been added to these figures and clarifying foot notes have been added wherever possible.

5.9 Qualification Test Program. The Qualification Test program for PAVE PAWS followed Military Standards for Preliminary Qualification Tests (PQT's) and Formal Qualification Tests (FQT's) and was carried out by a separate Functional Test organization. Each CPCI had one or more PQTs and an FQT. Performance requirements were mapped from the Part I Development Specification into Test Procedures for each test and then test scripts were developed to guide the conductance of each test. One early mistake on PAVE PAWS was to structure the PQTs along CPCG lines. This was not practical for several reasons: CPCGs don't normally execute all by themselves, and software development plans call for parallel development, which would result in PQTs being bunched at the end of the program. This approach was corrected by using the software development plan to determine what functions would be completed at various times and then defining a Test Procedure to address those functions. This allowed fairly even spacing of fully integrated functional tests.

The advantage offered by having a separate test organization is considerable. A comprehensive test program requires a considerable amount of planning, organization, and documentation as well as the tasks involved in actually running the tests and performing post-test analysis. These efforts can thus be accomplished without detracting from the programmer's day to day activities while at the same time a separate organization provides an independent outlook with respect to test plans and results. It is clear from PAVE PAWS experience that this is a key ingredient to a successful program.

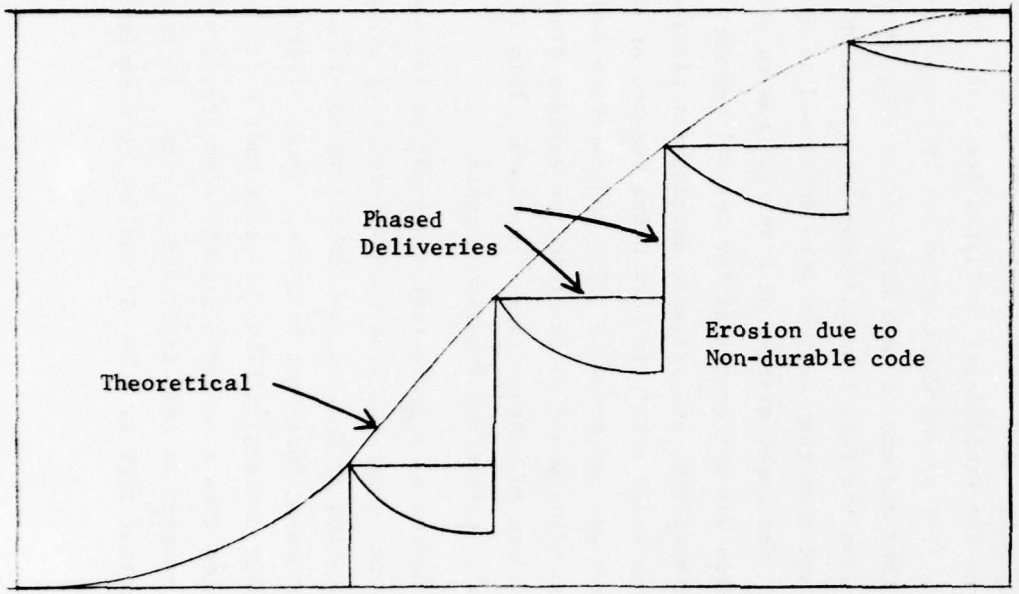


Figure 29. Code Development Curves

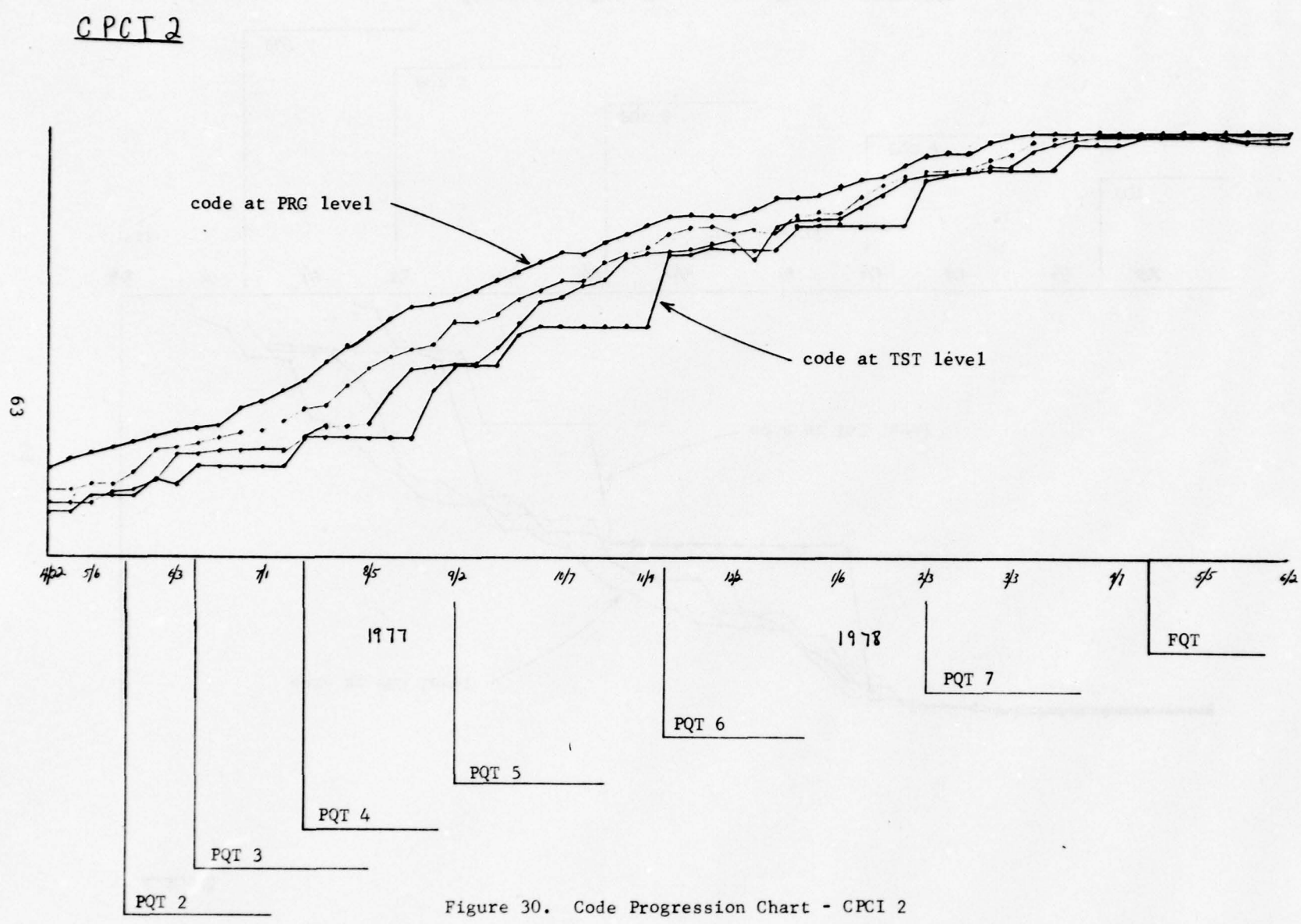


Figure 30. Code Progression Chart - CPCI 2

COMM

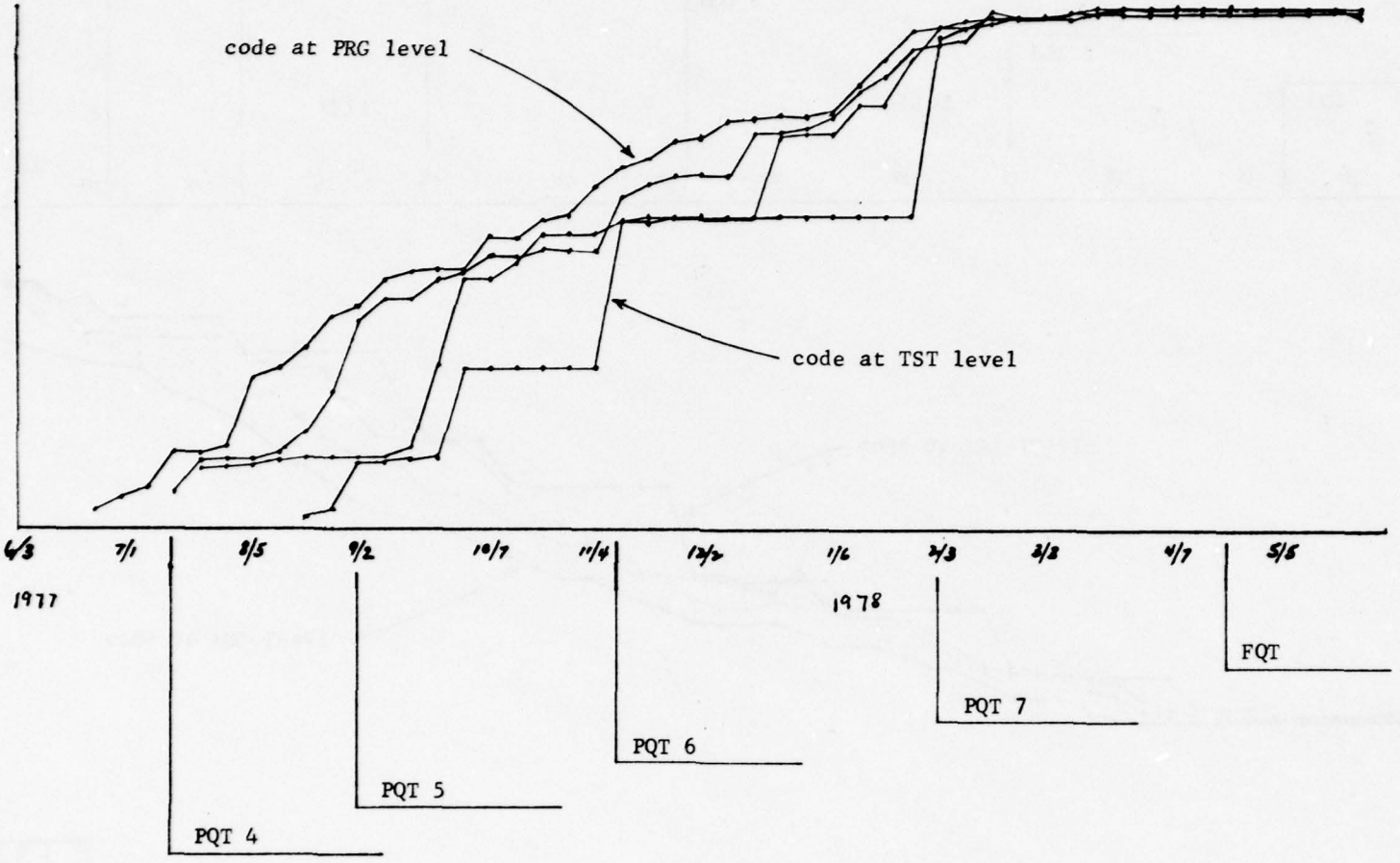


Figure 31. Code Progression Chart - COMM CPCG

DISP

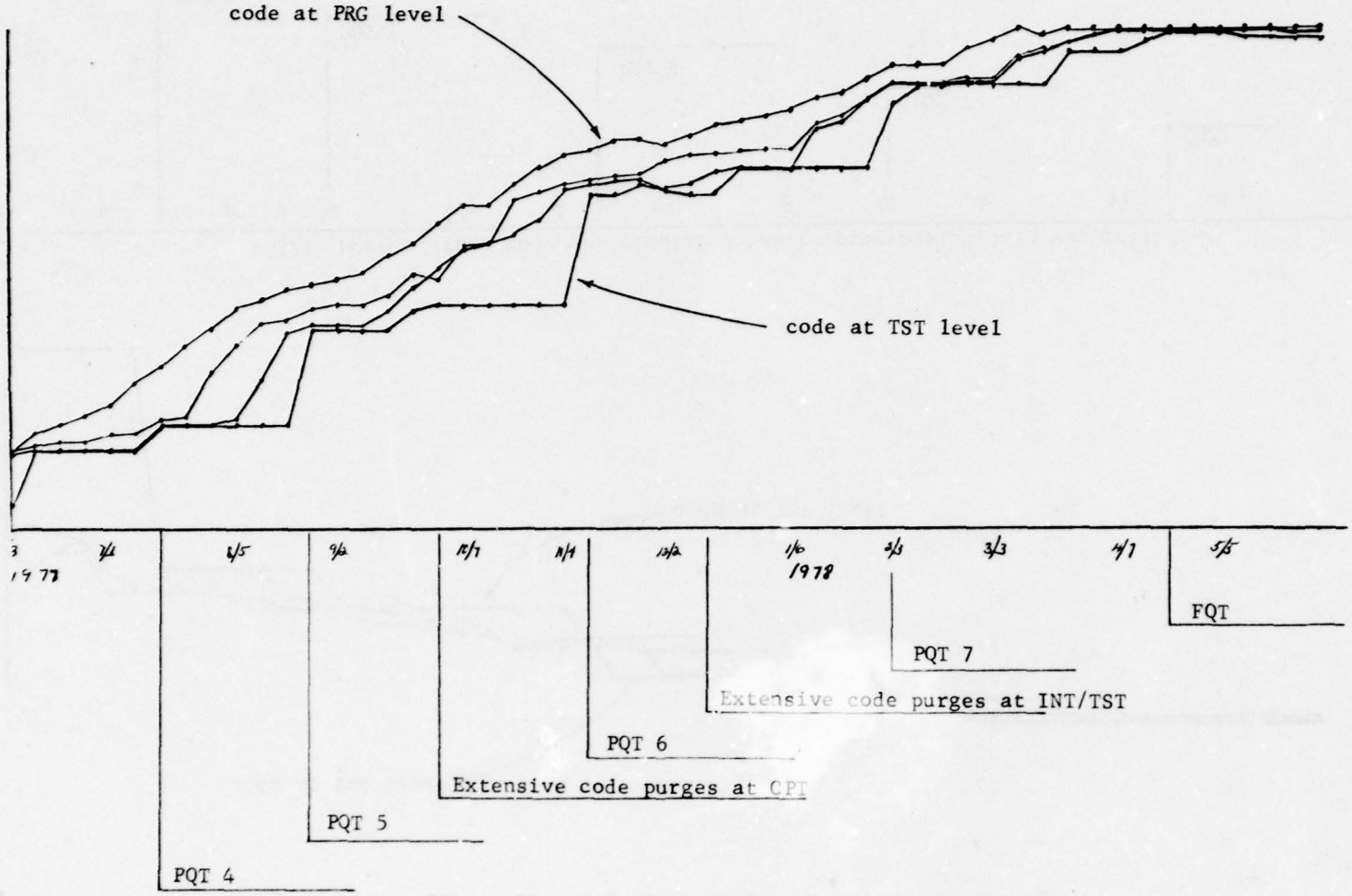


Figure 32. Code Progression Chart - DISP CPCG

MCTL

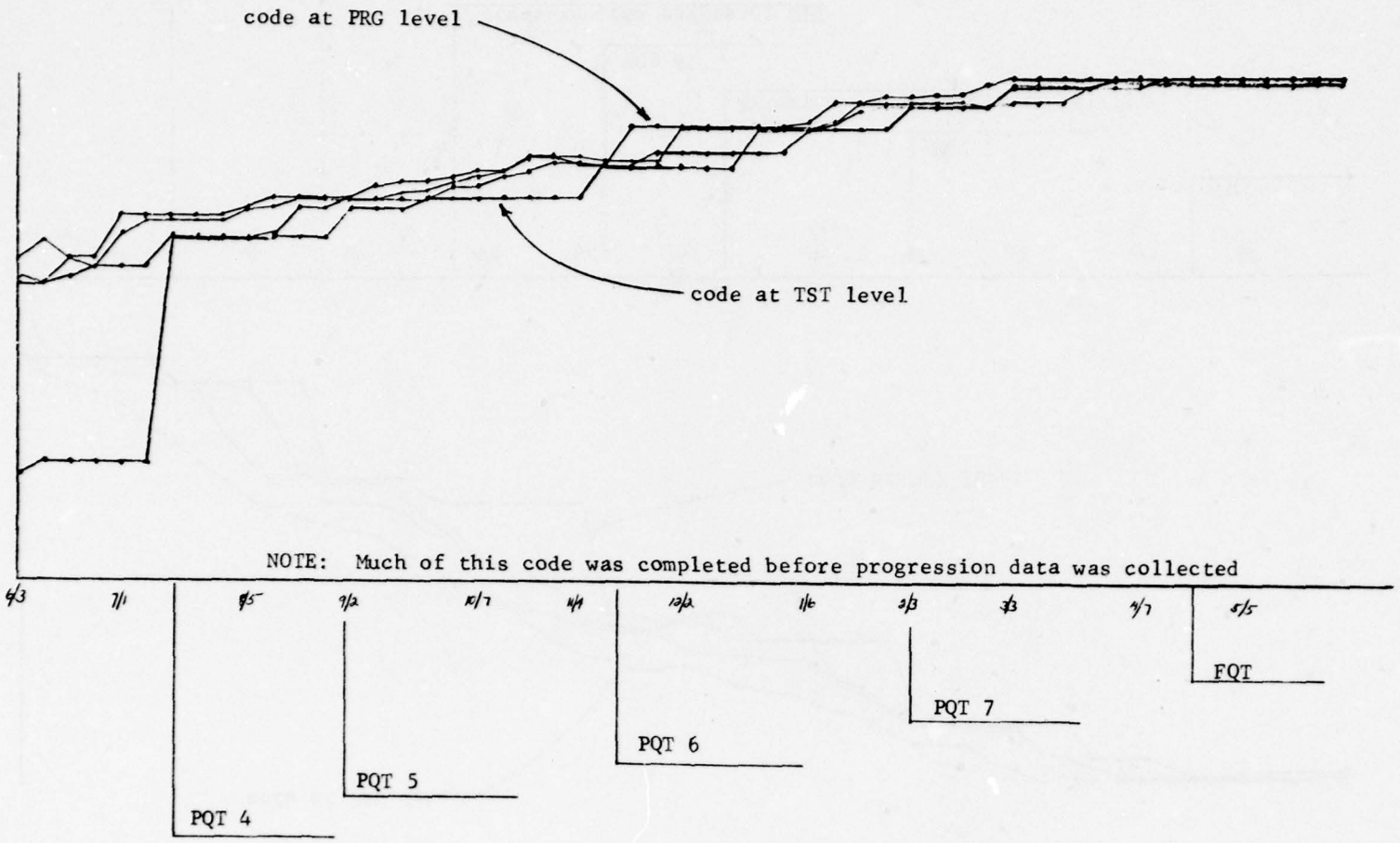


Figure 33. Code Progression Chart - MCTL CPCG

RAM

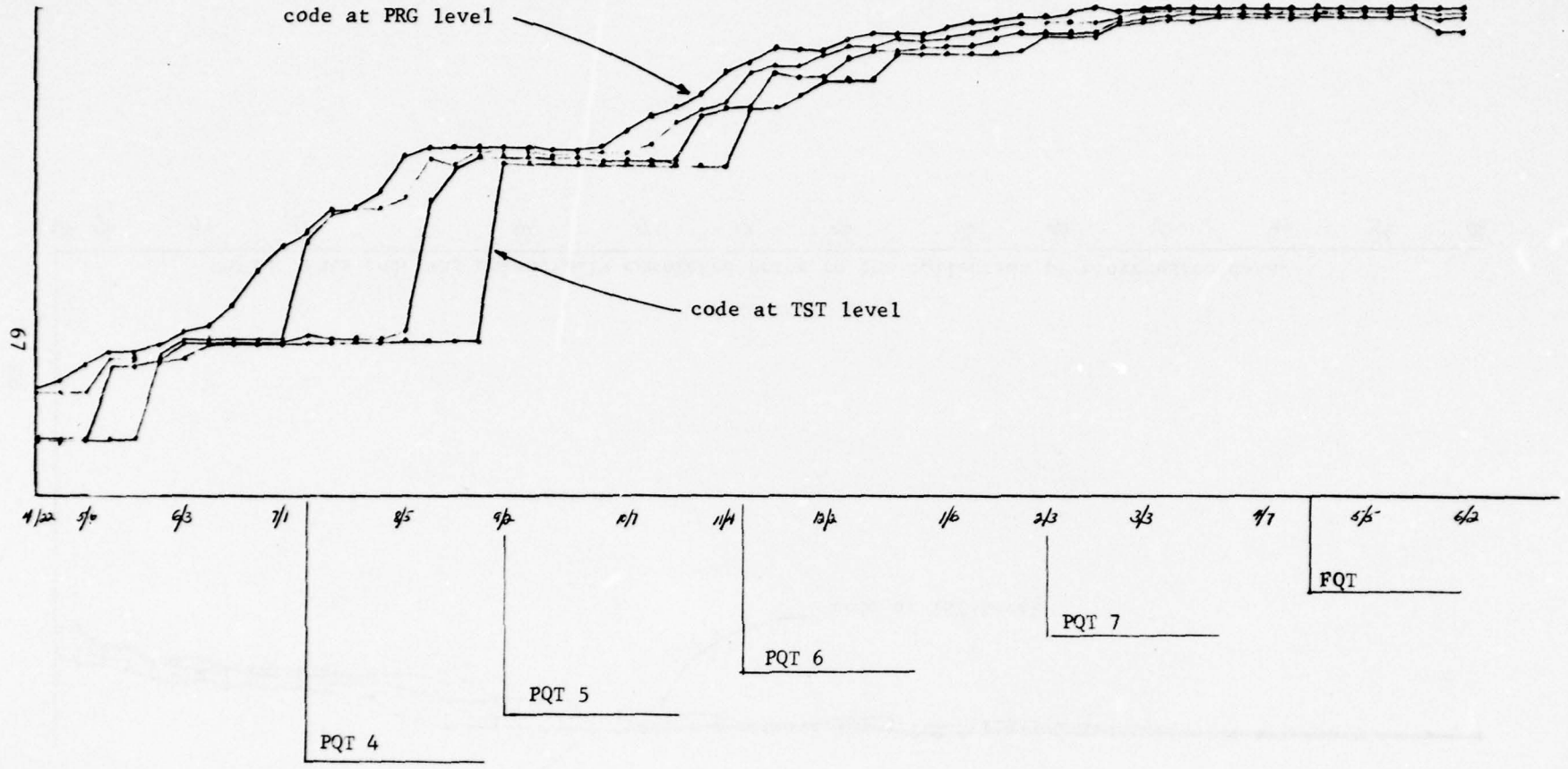


Figure 34. Code Progression Chart - RAM CPCG

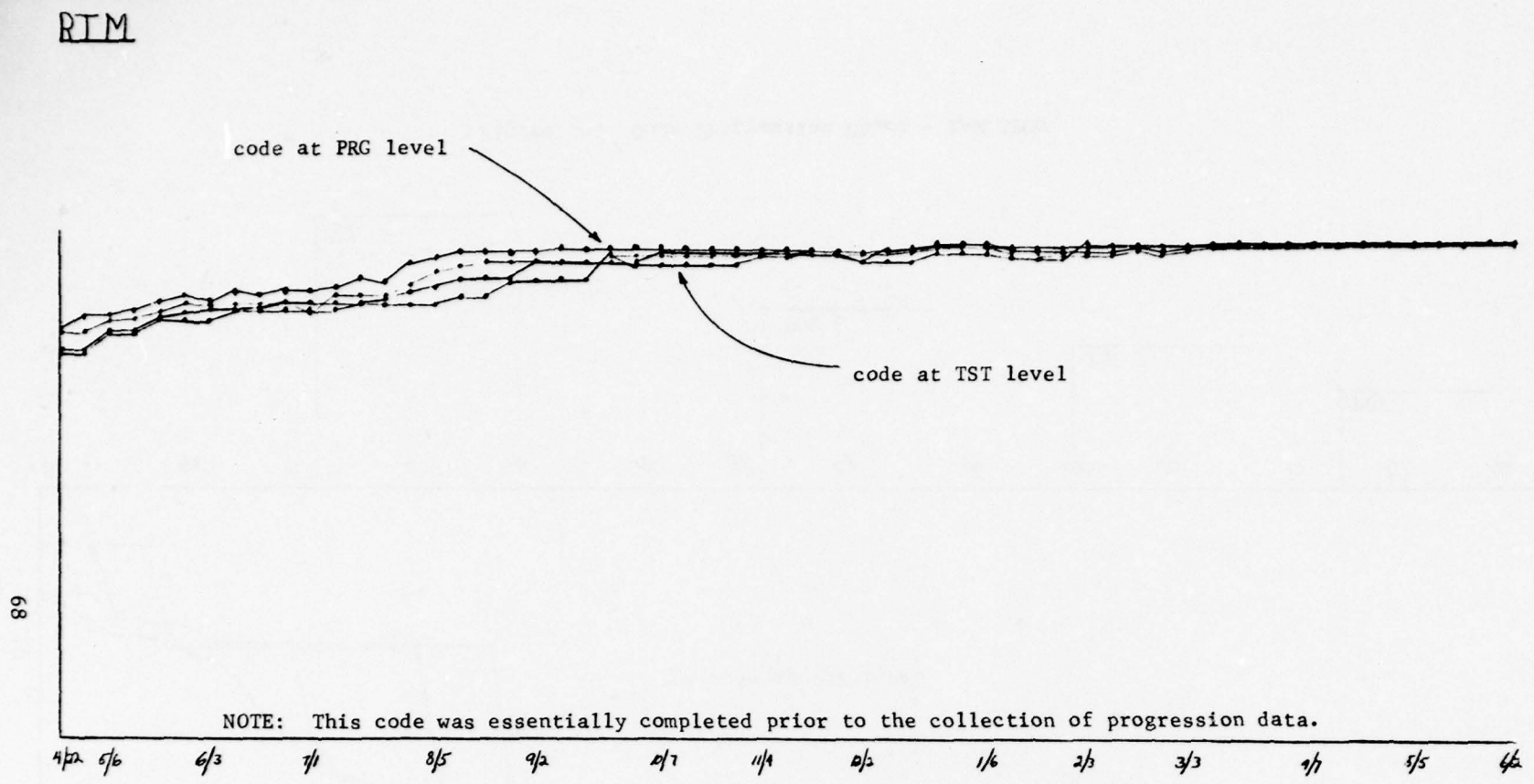


Figure 35. Code Progression Chart - RTM CPCG

SCM

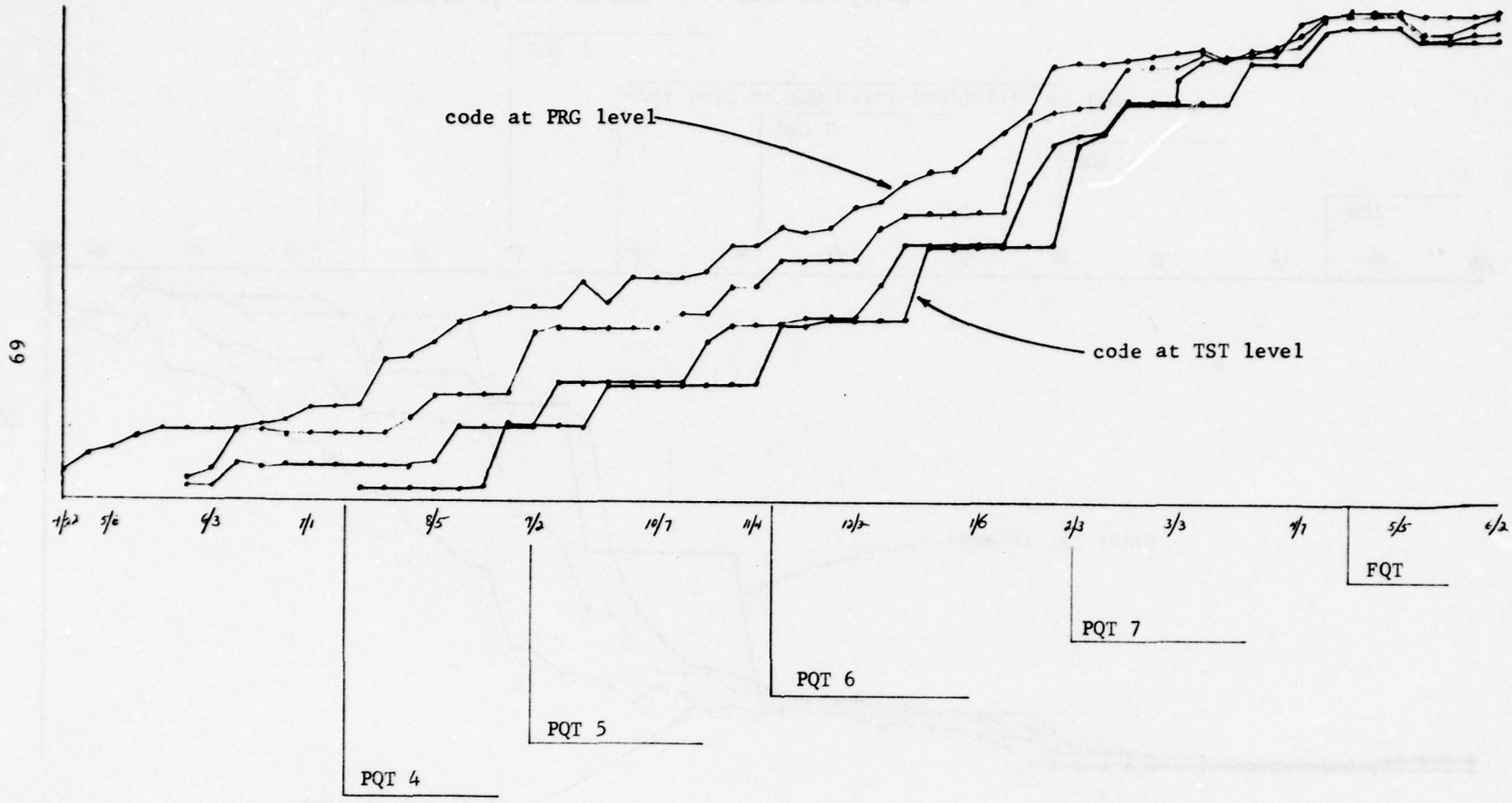


Figure 36. Code Progression Chart - SCM CPCG

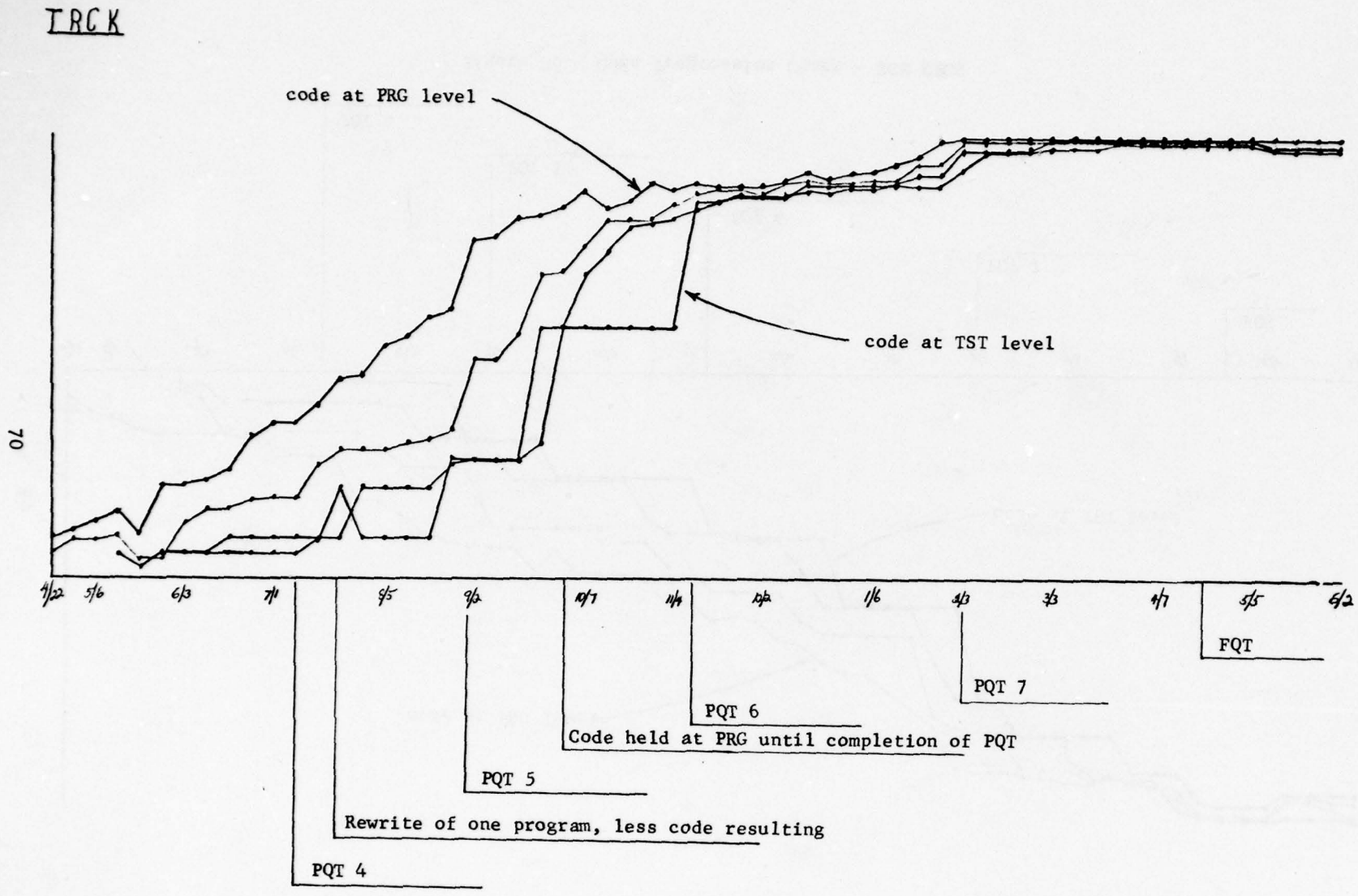


Figure 37. Code Progression Chart - TRCK CPCG

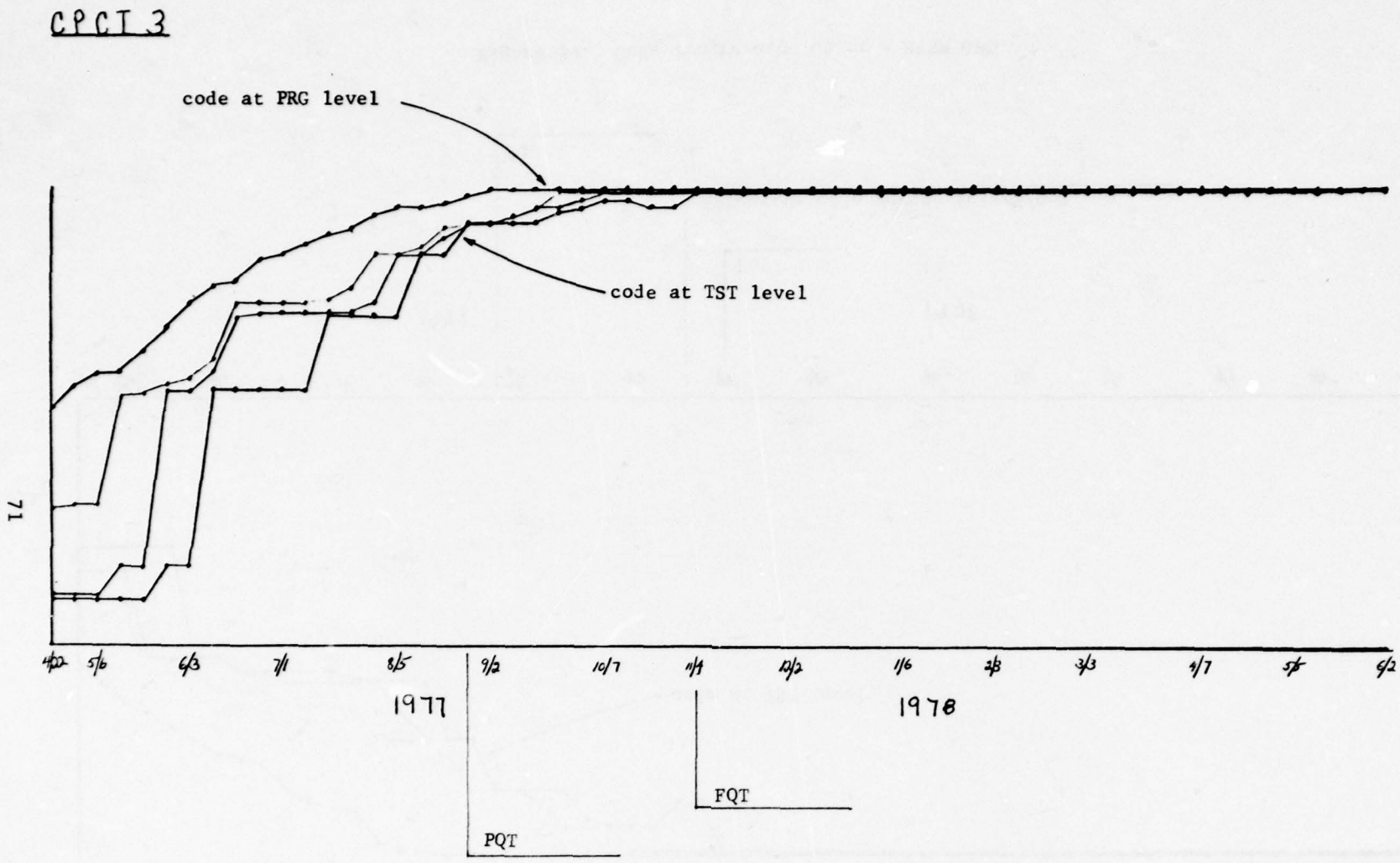


Figure 38. Code Progression Chart - CPCI 3

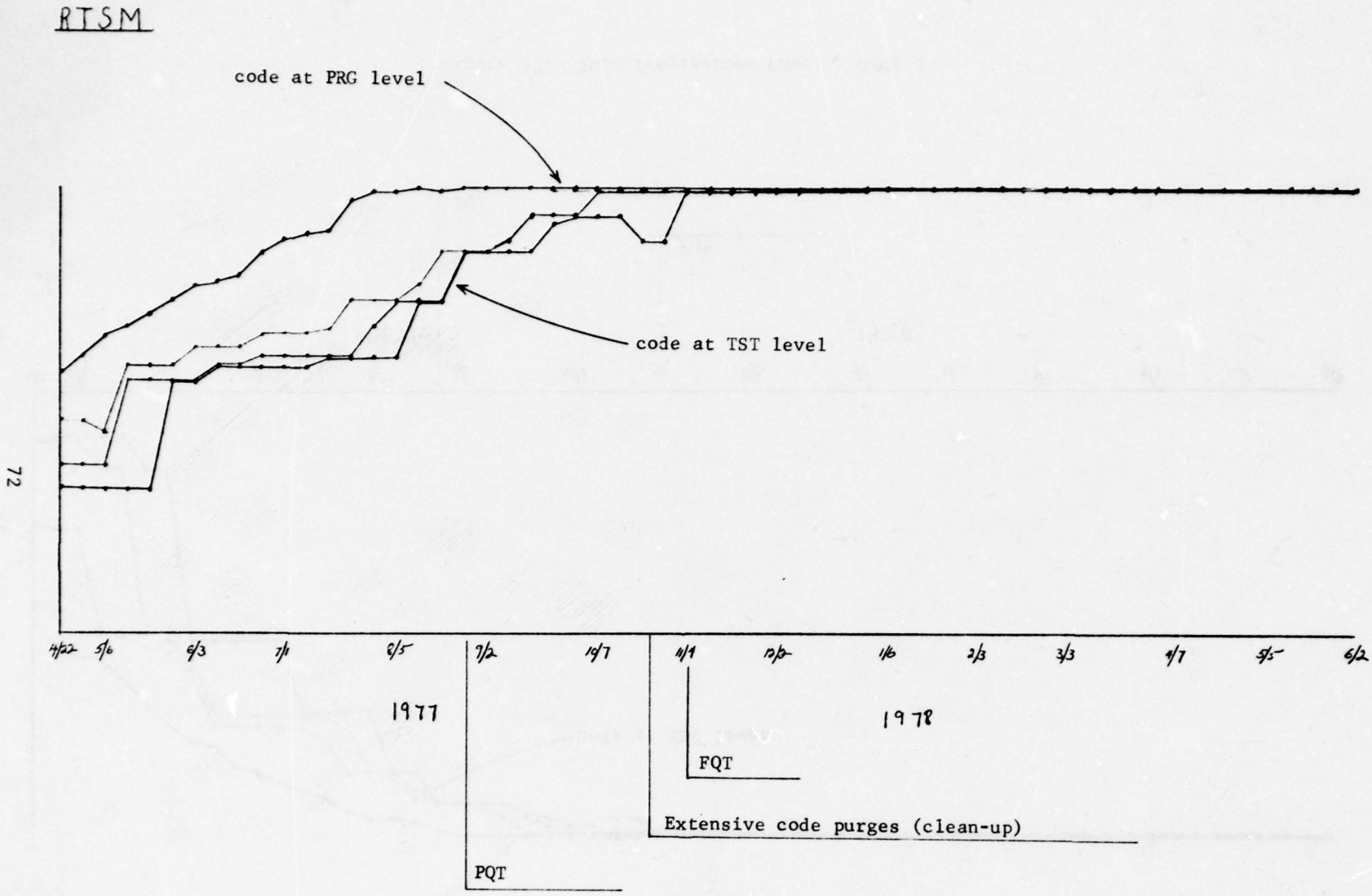


Figure 39. Code Progression Chart - RTSM CPCG

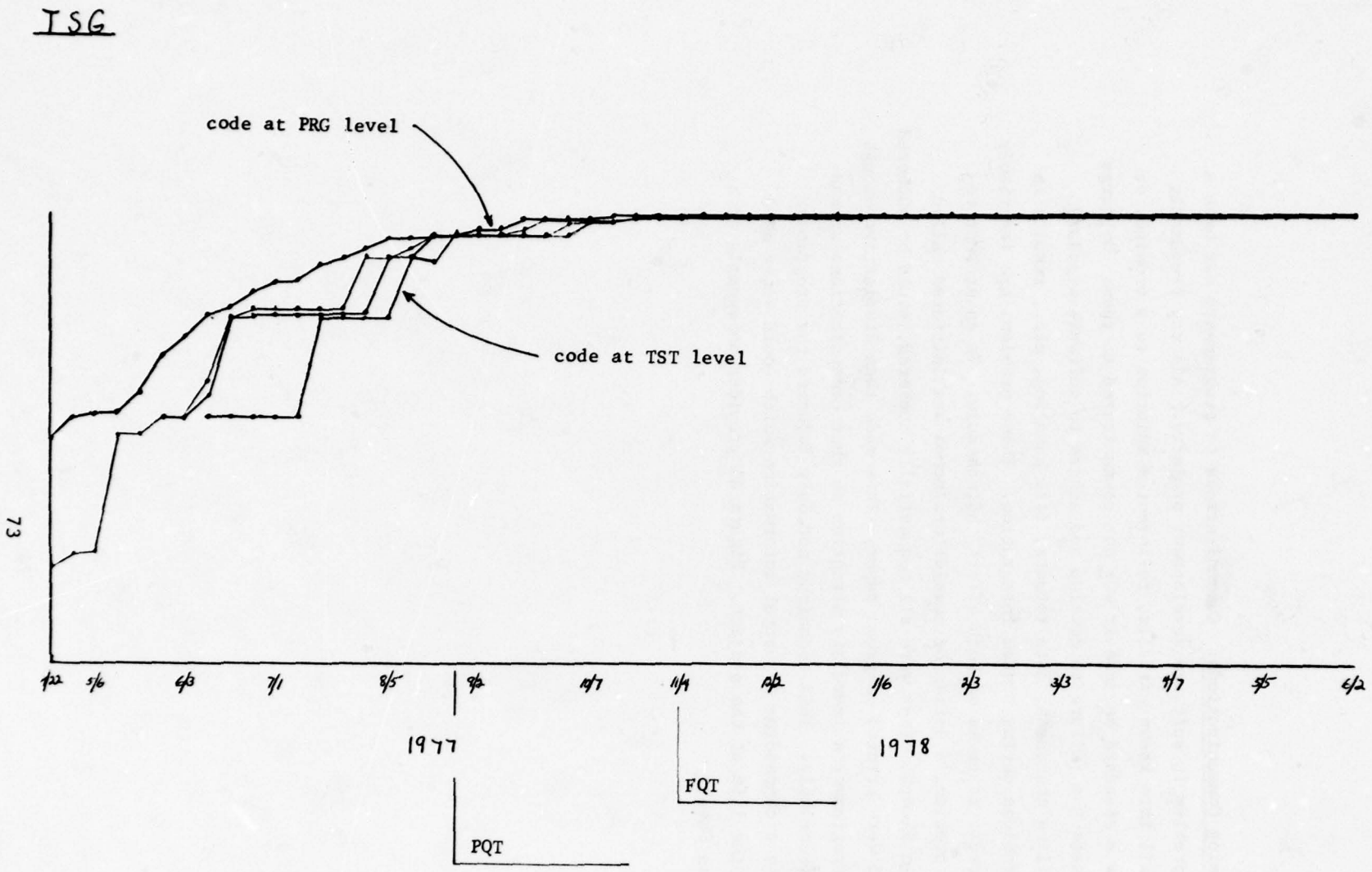


Figure 40. Code Progression Chart - TSG CPCG

5.10 Programming Communications. Communications to programmers has been a longstanding problem in software development projects. All too frequently programmers fall into known pitfalls, re-invent a solution to a problem, or fail to follow a standard because it was not communicated to them. On large software projects the failure to develop and adhere to software standards for names, calling sequences, data formats, file handling, etc., results in significant problems during system integration. These problems are invariably costly to correct, in terms of both effort and schedule. In an attempt to overcome this problem, a series of newsletters/memos was initiated called PAVE PAWS Green Sheets. They were all sequentially numbered, could be authored by anyone, and were printed on green paper. This made them distinctive enough to attract a programmer's immediate attention so that communications spread quickly and effectively. This technique not only informed the programmer but resulted in a compendium of useful information which could serve as a reference for the life of the project. Figure 41 provides an example of a PAVE PAWS Green Sheet.

*** PAVE PAWS' GREEN SHEET ***

NUMBER 6

DATE: 30 June 1976

AUTHOR: W. B. Vogdes

SUBJECT: Software Standard for PAVE PAWS Library Usage

This Green Sheet defines the software library hierarchy for PAVE PAWS and establishes the standard to be followed in its usage. Examples are provided for clarity.

The PAVE PAWS program library hierarchy is designed to support an orderly and well controlled progression of software from a development environment through integration and test and into a delivered status. Basic to this hierarchy are the concepts of control level and the migration of program elements from one level to another. A program element is ready to change control level when it has completed a predefined qualification criteria and is to be placed under more stringent change control. It is common practice for such a control structure to be established and the PAVE PAWS PSL maps that approach into the library hierarchy.

Seven levels of software control are utilized for PAVE PAWS (although additional levels can be readily created). See Figure 1 for a definition of those levels and the change authority associated with each one.

With this hierarchy, the programmer is able to retain access to multiple versions of a software element without losing any stability. Because the same program element may exist at more than one control level, it is necessary to specify both LONG.NAME and control level when referencing any library element (e.g., COMPILE LONG.NAME, LVL).

When programs are ready to enter the next change level they are XMIT'ed to that level. This is effected within the library by simply changing the control level associated with the software. The change authorization of the software is automatically changed at the same time. The process of software migration through development, integration, and test can thus be conceived as a "bubble-up" occurrence.

In order to facilitate changes to software which has already been XMIT'ed from one level to another, the PAVE PAWS PSL provides a feature called "automatic drawdown". This feature allows references to be resolved in the library either at or above the specified level. Output requests are always performed at the specified level. An example is illustrative.

Figure 41. Example of PAVE PAWS Green Sheet

PAVE PAWS' GREEN SHEET (Page 2)

NUMBER 6

Consider program LONG.NAME which consists of a top segment (T) and two INCLUDE'd segments (LONG.NAME1(S1) and LONG.NAME2(S2)). This program was developed at the PRG level and then XMIT'ed to CPT. The PRG and CPT levels appear as follows:

	(Contents)
CPT	T S1 S2
PRG	empty

Assume now that an error is detected in S1 which requires that it be corrected and undergo test at the PRG level. The segment may be updated and the program compiled using directives as follows (formats are for illustration only).

```
MODIFY LONG.NAME1,PRG
COMPILE LONG.NAME,PRG
```

During the MODIFY step, the PRG level will be searched to find S1. When it is not found, successively higher levels will be searched until it is found. In this case it is found at CPT and that will form the input source for the MODIFY. The updated source will be placed at the PRG level. Similarly, during the COMPILE step, both T and S2 will be "drawn-down" for input purposes. The object module output by the compiler will be stored at the PRG level.

The combination of control level hierarchy and automatic drawdown combine to make the PAVE PAWS PSL an easy to use yet hightly controllable system.

Figure 41. Example of PAVE PAWS Green Sheet (Continued)

	CONTROL LEVEL	SOFTWARE CHARACTERISTICS	CHANGE CONTROL
Delivery Libraries	DEL	Completely tested, delivered by Raytheon to AF	AF
	FRZ	Completely tested, delivered by IBM to Raytheon	Raytheon
Test Libraries	TST	Software undergoing PQT/FQT	Test Dept.
	FIX	Corrections to software in TST	Test Dept.
Development Libraries	INT	Software undergoing integration	Integration Mgr.
	CPT	Software under Chief Programmer's Control	Chief Programmer
	PRG	Software under development	Programmer

Figure 1. PAVE PAWS LIBRARY HIERARCHY

Figure 41. Example of PAVE PAWS Green Sheet (Continued)

6.0 CONCLUSIONS AND RECOMMENDATIONS

The software engineering and modern programming technology employed on the PAVE PAWS consists of an integrated set of tools and techniques. Utilization of this technology does not, in and of itself, guarantee the success of any program development, but does establish an environment to support project success. Top down design and implementation is effective in assuring that all system functions have been accounted for in the software design and assists in the tracing of system requirements from the highest level of mission functions to the lowest component of code produced. Benefits from commonality and standardization of coding techniques, naming conventions, and uniform presentation by indented listings contribute to programmer understanding within and among the groups established to code major system functions. This commonality enhances design and code reviews by providing a common frame of reference for discussion and continuity. Thus, program concepts and structure can be communicated between programmers and offers the greatest improvements to efficiency and effectiveness. The disciplined programming environment embodied in the modern programming technology used on the PAVE PAWS has measurably improved the transition of software development from the mysterious and arty to the clear and cohesive world of software engineering.

The PAVE PAWS hierarchical program support library represents an important technological improvement. The PSL itself is used by the programmer to enter, store, manipulate and transition software from design through development, test and integration, and delivery. At the same time, the PSL provides reports to management with the necessary visibility into the process. Thus, commonality exists between management and software production and further improves the probability of successful program completion by providing an environment for software stability and unhampered software development.

Two of the reports produced from PSL data merit further discussion. The Code Progression and Durability reports are of significant value to management. By examining these figures over a period of a week or month, code generation, integration and testing rates can be measured. Thus, when faced with a problem and an estimate of the resources needed for the solution, management is armed with objective measures to assess program impact. The report is a direct indicator of software quality and can be used to pinpoint areas where code is progressing too slowly or quickly. As far as is known, these measures of software quality are unique in the industry.

In summary, a number of modern programming techniques were utilized on PAVE PAWS and supplemented by software development tools which won widespread acceptance by programmers and managers alike. Although it must be realized that availability and use of this technology does not, in and of itself, guarantee success, it must be credited with establishing the environment to support project success. The experience gained is being fed back into both Raytheon and IBM business areas for consideration and potential inclusion in all future efforts.

APPENDIX I

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

GENERAL CONTRACT/PROJECT SUMMARY

1. Type of Contract: FFP _____ CPFF _____ OTHER FPIF

2. Total Cost (Actual or Estimated) $5.0M (CPCI's effort only)

3. Level of Subcontracting None

4. Project Environment

Dev. Team Collocated with User?	No
Dev. Team Collocated with Computer?	Yes
Dev. System Same as Operational System?	Yes
Test & Integration Separate Organization?	Yes

5. Project Description

Engineering support plus software design, fabrication, and test for

(1) PAVE PAWS Tactical Software (CPCI 2) which is a real-time system including input and output interfaces with the PAVE PAWS Radar Controller (RCL-CPCI 6) via the PAVE PAWS Operating System (PPOS-CPCI 1). The system has strict storage and throughput goals.

(2) PAVE PAWS Simulation Software (CPCI 3) which is a real-time system with the same interfacing requirements as above.

(3) PAVE PAWS Tactical Scenario Generator (CPCI 3) which is a non-real-time data base maintenance tool used to prepare scenario files used to drive Simulation.

(4) PAVE PAWS Data Reduction (CPCI 5) which is a non-real-time reduction system for a large variety of recording which is done by both CPCI 2 and CPCI 3.

(5) PAVE PAWS Program Support Library (PSL-CPCI 4) which provides the basic software library services in a topdown structured environment.

6. Project Start Date 04/12/76 Est. End Date 04/12/78

7. Estimated Number of Project Personnel

Management	_____	Systems Engineering	_____
Chief Programmer	_____	Functional Test	_____
Support	_____	Dev. Programming	_____

8. Estimated Number of CPC's 48

9. Estimated Number of Pages of Documentation

Requirements (Part I)	1460	Test Reports	1200
Specifications (Part II)	3400	User Manuals	900
Test Specifications	2000	Other	600

10. Estimated Total Number of Instructions N/A Cards 135K

11. Estimated Number of Different Input Formats N/A

12. Estimated Number of Different Output Formats N/A

13. Estimated Total Man/Months

Management	85	Programming	630
Support	102	Test	170
Engineering	102		

14. Estimated Total Computer Time (HRS) 7000 Hours
(wall clock on dedicated computer)

Contact B. Scheff (Raytheon)

APPENDIX II

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

MANAGEMENT METHODOLOGY SUMMARY

1. Management Procedures/Tools Used

   PAVE PAWS Program Support Library (PSL) reporting

   PAVE PAWS Trouble Report Procedures

   Program Control Management System (PCMS - Financial)

2. Documentation Available at CDR:

   a. Development Specification (Part I) - CPCI 2
   b. Development Specification (Part I) - CPCI 3
   c. Development Specification (Part I) - CPCI 4
   d. Development Specification (Part I) - CPCI 5
   e. Product Specification (Part II) - CPCI 2
   f. Product Specification (Part II) - CPCI 3
   g. Product Specification (Part II) - CPCI 4
   h. Product Specification (Part II) - CPCI 5

   Note: All above documents provided to customer.

3. Formal Reviews and Schedule

		Date	
a.	CPCI 2	PDR 8/76	CDR 1/77
b.	CPCI 3	PDR 8/76	CDR 1/77
c.	CPCI 4	PDR 7/76	CDR 9/77
d.	CPCI 5	PDR 8/76	CDR 1/77

4. AF Regulations, Manuals, and Military Standards Under Which Development Will Be Conducted

   MIL-STD-483

   MIL-STD-490

   MIL-STD-1521

5. Description of Deliverable Software

Refer to GENERAL CONTRACT/PROJECT SUMMARY, Item 5, for an overview of the technical content of deliverable software. All software will be delivered in a PSL form (either disk or checkpoint tape).

6. Reference Measurement Gathering Procedures

Clarification required.

Contact B. Scheff (Raytheon)

APPENDIX III

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

DESIGN AND PROCESSOR SUMMARY

1. Target Computer(s) CDC CYBER 174-12
(same as development computer)

2. Processing Environment

1 Card Reader (CDC 405)
2 Line Printers (CDC 580-12)
3 Disk Drives (CDC 844-21)
6 CRT's (CDC 774-1)
1 Plotter (Gould)
6 Tape Drives (CDC 669-2)

3. Configuration: Hands on X Batch ___ Remote ___ On-line ___

4. Operating System(s) Version Nos. 1.0 as modified (PPOS)

5. Compiler Version(s) JOVIAL J3

6. Assembler(s) COMPASS

7. Est. Percent: JOVIAL 85 COMPASS 15

8. Automated Software Tools Used: PAVE PAWS PSL

9. Design Standards

- MIL-STD-483, Appendix VI
- IBM FSD Software Standards (33-09)

10. Programming Standards

- PAVE PAWS Green Sheets
- PAVE PAWS Computer Development Plan

11. Programming Techniques Employed:

Topdown Design	X	HIPO	X
Chief Programmer	X	Structured Code	X
Librarian	X	Structured Walk Thru	X
Topdown Test	X	Other - PDL	X

12. List Existing Programs/CPC's to be Used Standard commercial software

13. Estimated Turnaround Time (HRS): Batch 2 Hours

Contact B. Scheff (Raytheon)

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #1

(See Table Below for Detail Breakdown)

	TITLE	EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
		HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	NOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	5	BS	x			14	1					14	FTN/FAP/SOS/RAL-S/360,7090,7094,CLC
2	BACKUP	4	4	AB	x			13	7	2			5	10	COBOL/PL1/ASSEMBLER - S/360, CDC 160A,UNIVAC 1107, B5000
3	MEMBER	4	2	AA	x	x		2	2					3	PL1/RAL/CENTRAN, SNX - S/370, CLC
4	MEMBER	4	4	BA	x			3						3	PL1/CENTRAN/SNX/BAL - S/370, CLC
5	MEMBER	4	0		x			2						2	CENTRAN/SNX - CLC
6	MEMBER	4	4	BA	x			3	4					5	FTN,RPG,BASIC,CENTRAN,SNX - S/360, S/370, CLC
7	BACKUP	4	6	BS	x	x		12						12	ALC, FTN, PL1 - S/360, S/370, 1401, 1410, 1620

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

SYSTEM PAVE PAWS (Data Collected Again) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #2

(See Table Below for Detail Breakdown)

		EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
	TITLE	HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	NOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	4	BS	x			9	9				2	9	CENTRAN, SNX, PL1 - S/360, CLC
2	BACKUP	4	4	AB	x			13	7	2			5	10	COBOL, PL1, ASSMBLR - S/360, CDC 160A, UNIVAC 1107, B500
3	MEMBER	4	5.5	MA	x			8						5	PL1, BAL, FTN, CENTRAN, SNX - S/360, CLC, 4PI
4	MEMBER	4	4	BA	x			3	4					5	FTN, RPG, BASIC, CENTRAN, SNX - S/360, S/370, CLC
5	MEMBER	4			x		7	1.5						1.5	PL1, CENTRAN, SNX - S/360, CLC
6	MEMBER	4	4	BS	x			1.2						1.2	FTN, PL1, COBOL, BAL, RPG - S/360, 1130, S/3
7	MEMBER	4	4	BA	x			20		5				6	FTN, PL1, BAL - S/360, S/370, 9020, PHILCO 2000

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #3

(See Table Below for Detail Breakdown)

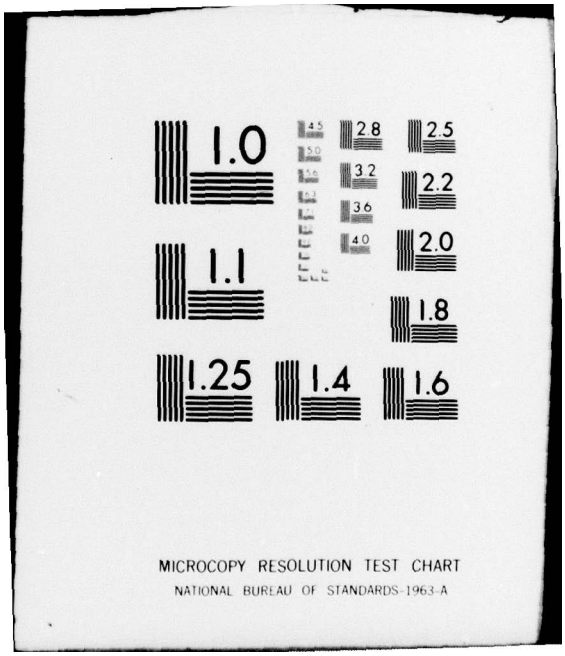
	TITLE	EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
		HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	NOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	1.5		x			13						6	FTN, PL1, NIPS, CENTRAN, SNX - S/360, 1401, CLC, UNIVAC 490
2	BACKUP	4	3		x			15						15	PL1, COBOL, FTN, APL - S/360, 1401, 1410
3	MEMBER	4	4	BS	x			8						6	FTN, PL1, CENTRAN, SNX - S/360, S/370, CLC
4	MEMBER	4	4	BS	x			9					6		FTN, PL1, PLS, APL, BAL - S/360, 1620, 1130, 7094, 9020
5	MEMBER	4	2		x	x	3	2						5	BAL, PL1, CENTRAN, SNX - S/360, CLC

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

AD-A073 357 RAYTHEON CO WAYLAND MA EQUIPMENT DIV F/G 9/2
PAVE PAWS MODERN PROGRAMMING DATA COLLECTION SYSTEM.(U)
JUN 79 B H SCHEFF, W B VODGES, N R HALL F30602-77-C-0141
UNCLASSIFIED RADC-TR-79-137 NL

2 OF 2
AD A073857

END
DATE FILMED
10-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #4

(See Table Below for Detail Breakdown)

	TITLE	EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
		HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	NOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	4	MS	x	x		11						4	FTN, PL1, CENTRAN, COBOL, BASIC - S/370, CLC
2	MEMBER	4	2	AA	x	x		5.5		2				4	FTN, COBOL, RPG, CENTRAN, SNX - S/360, CLC
3	MEMBER	4	1		x	x		3	2	10				3	BAL, PL1, CENTRAN, SNX - S/360, CLC
4	BACKUP	4	4	BS	x	x		8.5						6	BAL, PL1, CENTRAN, SNX - S/360, CLC
5	MEMBER	4	2		x	x	3	2						5	BAL, PL1, CENTRAN, SNX - S/360, CLC

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #5

(See Table Below for Detail Breakdown)

	TITLE	EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
		HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	MOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	4	BS	x			4	2	2				8	CENTRAN,SNX,BAL - S/360, S/370, CLC
2	BACKUP	4	5	MS	x	x		10						5	CENTRAN,SNX,PL1,BAL - S/370, CLC
3	MEMBER	4	8	MA	x			4	4					8	FTN,BAL,CENTRAN,SNX - S/360, CLC
4	MEMBER	4	5	BA	x			5						3	PL1,APL,FTN,COBOL,CENTRAN,SNX - S/360, CLC, CDC 6600, 1620
5	MEMBER	4	6	BS	x			16						16	FTN,BASIC,ASSMBLR - 704, 7044, CDC 6000, UNIVAC 8300
6	MEMBER	4	4	BA	x			3						3	PL1,CENTRAN,SNX,BAL - S/370, CLC
7	MEMBER	4	6	MB	x			1.5	3.5					5	BAL,PL1,CENTRAN - S/360, CLC

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

SYSTEM PAVE PAWS (Data Collected Against) DATE 10/07/77

PERSONNEL PROFILE

CHIEF PROGRAMMER TEAM #6

(See Table Below for Detail Breakdown)

	TITLE	EDUCATION			TARGET LANGUAGE		EXPERIENCE				EXPERIENCE				EXPERIENCE
		HS	COLL	DEG	JOV	COMP	OPNS	PGMG	ANAL	OTHR	CYBER	NOS	JOV	SMLR	LANGUAGES AND COMPUTERS
1	CHIEF	4	6	MA	x			9						9	BAL,FTN,PL1,CENTRAN,SNX - S/360, CLC
2	BACKUP	4	6	MS	x			5.5	0.5					3.5	FTN,PL1,CENTRAN, SNX - S/360, SIGMA 7, CLC
3	MEMBER	4	2	AA	x	x		2	2					3.	PL1,BAL,CENTRAN,SNX - S/370, CLC
4	MEMBER	4	7	BS	x		1.5	1	1.5					2.5	CENTRAN,SNX,PL1 - S/360, CLC
5	MEMBER	4	7	MS	x			6						4	FTN,COBOL - S/370, DEC PDP-15, UNIVAC 1108

NOTE: Essentially all members of this team have completed a nine week Basic Programmer Training course after they were hired. They have additionally completed a variety of IBM sponsored courses, including Structured Programming.

MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.